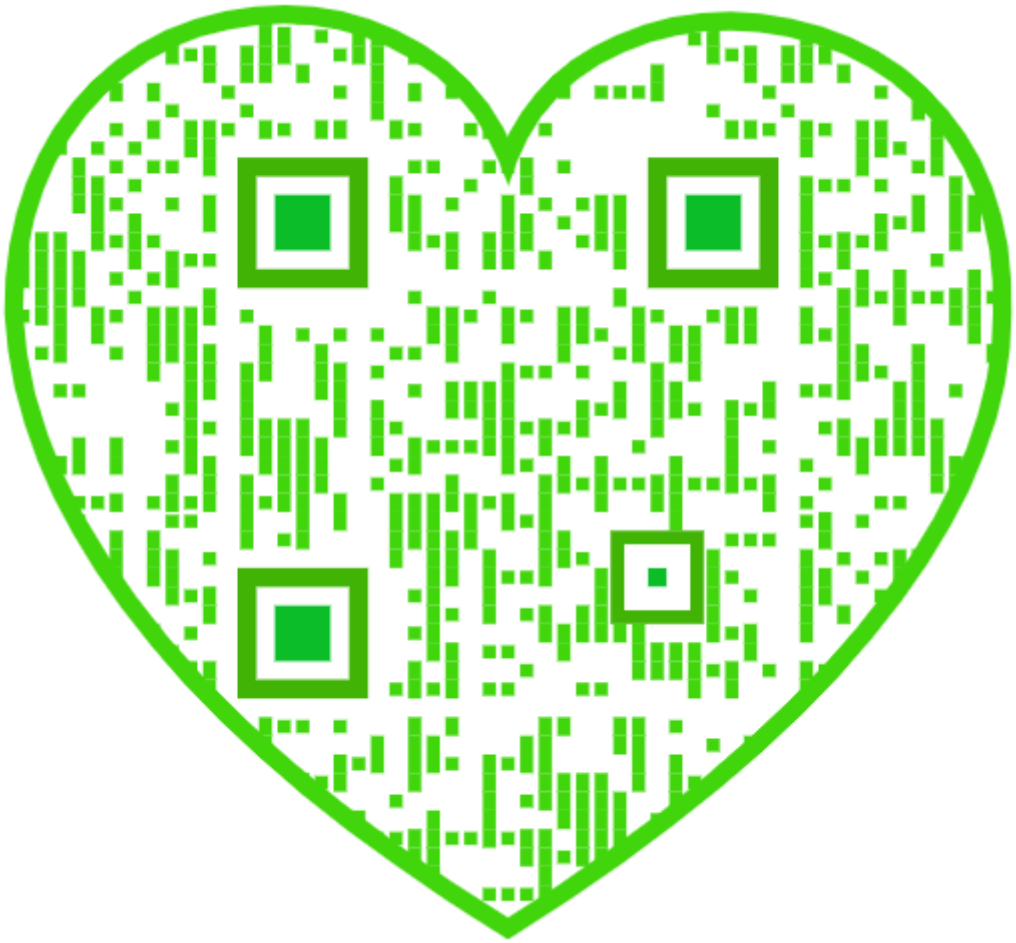

SEWERS AND DRAINS

FOR

POPULOUS DISTRICTS;

WITH

RULES AND FORMULÆ

FOR THE DETERMINATION OF THEIR DIMENSIONS

UNDER ALL CIRCUMSTANCES.

BY

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PREFACE.

IN 1857 the author was charged with the preparation of plans for the sewering of the City of Brooklyn, covering an area of twenty square miles, a great portion of which was then suburban territory. At that date we were totally without data of any kind in this country to guide in the determination of the proper dimensions of sewers for the drainage of cities and towns. No gaugings had ever been made of the discharge of sewers, and the only principle recognized, was to make the sewers large enough to admit of the entrance of workmen to clean them by the use of the pick and shovel; so little had the subject occupied the attention of engineers that it was scarcely thought within their province, in this direction, to do more than to see to the proper construction of what was determined upon by property owners, city surveyors, or municipal councils.

In 1852 the General Board of Health under the Public Health Act had made their first Report to the British Parliament, and advocated very strongly the introduction of smaller pipes in lieu of the large brick and stone drains heretofore in use for house-drainage. Prior to this date (1847) the first Report of the Metropolitan Sanitary Commission, London, appeared, which while not to be taken as advocating exclusively the use of small pipes, yet pointed out the necessity of reducing the dimensions, and altering the shapes of the old stone and brick structures. Embodied in the Board of Health Report above referred to, were tables of the sizes recommended for sewers and drains for specified areas and inclinations, and which claimed to be the result of over twenty years experience in detailed observations of the working of sewers and repeated and multiplied gaugings of the London sewers under all circumstances of storm-water discharges. These tables, issued under such undoubted authority, were calculated to command attention here, and were republished very extensively, indeed wherever works of sewerage were projected in this country, and they were largely instrumental in bringing about the use of burnt clay pipes for sewers,

and in creating the impression (which we cannot say was the aim of the Report) that the business of draining and sewering towns was a very simple affair, and which an attention to the proper use of these Tables would enable almost any one to direct successfully. These Tables did not find universal favor with Engineers, as might be supposed; but the facts embodied in them, being given in evidence before committees of Parliament, could not be gainsaid, however startling some of them might appear, and with a certain class of practitioners they were largely accepted, but for some time past have ceased to be considered as standard; and failing any acknowledged standard, engineers have been left free to adopt such principles to guide them in the dimensions of sewers as their individual judgment might dictate.

Within a few years past (1873) an exhaustive treatise has appeared from the English press, which has passed to a second edition, explaining with much detail the practice of its author in the construction of sewers, and basing his estimate of their discharge upon the hydraulic formula for water discharge from a Reservoir.

This errs as much on the other side, as did the Board of Health Report Tables in its advocacy of extremely small sewers for populous districts; and in other respects, if followed as a standard in this country, it would lead to an aggravation of the very form of nuisance which it was the design to obviate; and still further, the cost of sewerage works (no inconsiderable item in a new country) would thereby be enhanced beyond what the necessities of the locality call for.

In advocating the importance of simplicity and cheapness in works of sewerage we do not mean the use of second rate materials or workmanship, neither of which should find place in any works of sewerage, but we refer to the economy which results from the adoption of methods of design, strictly suited in character, materials and workmanship in the simplest manner, to the end in view.

To illustrate the importance of this economy, we quote from a Report on the Philadelphia sewers published in Van Nostrand's Magazine for 1878, p. 429, wherein it is stated that "the Sewers of that city are designed to carry off one inch of rain per hour, and that the Mill Creek Sewer, draining 3000 acres, requires a diameter of twenty feet for two miles in length. The Heart Creek Sewer draining 2000 acres is from 13 to 16½ feet in diameter for two miles, and

the Honey River Sewer, which will drain over 4000 acres when completed, has already a diameter of fourteen feet, *six miles above its ultimate probable outlet.*" Upon what formula for the discharge of conduit these dimensions were determined we are not informed; but the opinion is given in the Report that the continuation to completion of the works as designed (which are not referred to as by any means fulfilling the requirements of the locality) would be attended with an unnecessary expenditure involving millions of dollars!

As indicating what we regard as the principle underlying a proper system of city sewerage and drainage, we quote from the last edition of "Hydraulic Tables by Neville" (an English engineer of deserved celebrity in his branch of the profession) as follows:

"It is too often taken for granted that the discharge from a catchment basin takes place into the converging channels in nearly the same time that a given quantity of rain falls. The quantity which falls will not be discharged into the channels in the same time. The arterial channels receive the supply at different places, and from different distances, and the water in passing into and from it, does not encounter the same amount of resistance as if it all passed first into the upper end. Less sectional area is therefore necessary than if the whole discharge had to pass through the whole length of the channel, and during the time of fall. The relation of the quantity of rainfall to the portion which flows into the main channel, as well as the time which it takes to arrive at it, and the places of arrival, must be known before the proper size of a new channel can be determined, *particularly sewers in urban districts.*

"A pipe sufficient to discharge the water from 200 acres, need not be of twenty times the discharging power of one exactly suited to ten acres of the same district; for the discharge from the outlying 190 acres, will not arrive at the main in the same time as that from the adjacent ten acres."

We are not aware of the proper recognition of this principle heretofore, and the constant enquiry for detailed information in relation to the system of sewerage pursued in the City of Brooklyn has led to the preparation of this volume, which embodies the principles and practice of sewering towns and cities as illustrated in the successful working of the system adopted there, based upon a recognition of the above principle as enunciated by Neville, and which has proved to be so far successful that an experience of over

twenty years points to no modification being called for in the original design or scheme beyond matters of detail. There are of course minor defects apparent, but we believe the remedy for them is pointed out in these pages. We took as our guide for these works the English system of "water-carriage," and can lay no claim whatever to invention or originality of plan; and if any measure of success has followed our efforts here, it has arisen from the free use of information derived from the reports and practice of such distinguished men as Sir Joseph Bazelgette, Mr. Thomas Hawksley Mr. Wm. Haywood, Mr. James Rawlinson, and other English engineers, to whom we beg leave to make our acknowledgments.

We have omitted in these pages the introduction of Tables and formula for the stress and strength of materials, etc., and other matters which, while applicable in many cases to sewer construction, are at the same time of universal use in most branches of construction; and it is to be presumed that the engineer does not seek in a work on sewers and drains for general information in his profession, but for something specific, and hence the author has restricted himself to the matter in hand, which he has undertaken, if not to simplify, certainly to remove some of the unnecessary complications with which it has hitherto been hampered.

155 CONGRESS ST., *Brooklyn, New York.*

CHAPTER I.

INTRODUCTION.

ALTHOUGH Sanitary Science, as we understand the term, is of modern growth, and it is only within the last thirty or forty years that the subject has engaged the attention of scientific men, yet the remains of ancient works exhibit the fact, that so soon as the progress of civilization tended to concentrate population within centres of comparatively limited areas, it was discovered that the greatest enemy to man's comfort, if not his health, was man himself; and the best method for the prompt removal of noxious refuse from the vicinity of his dwelling, which to the primitive inhabitant was a subject scarcely worthy of a thought, soon forced itself upon his attention as a subject above all others deserving of his careful consideration.

Late explorations in Jerusalem have brought to light most extensive arrangements for the removal from the vicinity of the Temple of the offensive matters peculiar to the bloody sacrifices of that ancient people; and the famous Cloaca Maxima at Rome, built under the Tarquins for the purpose of the drainage of the imperial city, and at a time when its inhabitants were content to live mostly in huts, together with evidences of works of sewerage in other ancient cities, all point to the fact, that if the subject of sewerage was not treated scientifically in those times, its importance at least was recognized.

Vitruvius, a writer in the time of Augustus, enlarges upon the importance of thorough drainage for the sites of

towns, and even encampments, and states the means adopted by the Romans for the thorough sewerage of even their provincial cities; and the care shown in ancient Rome that the sewers should be proportioned to the service expected of them, enlarging gradually from their extremities, through all the ramifications of the system, until they finally reached the outlet, shows a comprehensive scheme, and evidently under central management (and not as in a sister city, where, until lately, the residents of a street determined the dimensions of their sewer, irrespective of what might lead into it, or into what it might lead); and yet, with all this evidence that the health of the people was a care on the minds of their rulers, as far back in history as the evidence exists of any crowded population in a given locality, we may say that sanitary science is a modern one, precisely as we may say that all science based upon the knowledge of chemical laws must be modern. Recollecting that carbonic acid was not discovered until 1757, hydrogen in 1766, and oxygen in 1774, we can see how the sanitary precautions taken by the ancients could not have arisen from their knowledge of the laws which governed matter in the various changes which accompanied decomposition. The bare fact that the result of such changes was disagreeable to one of the senses, and experience had shown was injurious to health, was all they had to guide them.

With the light of modern science, the rule of thumb process was no longer satisfactory, and it was evident that sanitary measures, in order to be effectual, required a recognition of certain elementary laws of matter which had hitherto remained in obscurity. This brought the subject within the domain of science, and sanitary science has now become a recognized branch of medical study, as sanitary engineering has become a branch of the art of construction.

Sanitary Science should be regarded simply as an aid to nature in dealing in a proper manner with those compounds which are constantly being eliminated from the animal system, and which are fitted to become the food of the vegetable kingdom, which in its turn utilizes those waste elements from animal life, and after utilization retains only those substances which are needful for their own sustenance, thus giving back the original elements in a healthful state, and fitted for the uses of animal life.

Properly to appreciate the scope of this science, a notice of the animal economy of man in relation to the materials from which he derives his sustenance, and the chemical changes which render these materials detrimental to his health, would be in place, but the subject is a wide one, and cannot be treated save incidentally in these pages, which will be confined to—

"Sanitary Engineering," which consists in the constructions which are called for in facilitating the purification of the air—removing dangerous impurities from water—supplying an abundance of both of these life-giving elements, and removing as speedily as possible, before decomposition commences, all refuse matter, whether of animal or vegetable origin. Beginning with the last, as involving in its results, if properly carried out, the attainment of all the others, we have for consideration—the proper method for the disposal of the refuse from our cities.

The importance of effective drainage and sewerage has been shown in so many reports from professional men and government commissions, that its influence on health, strength, and length of life is gradually beginning to be generally understood. The results of all inquiries abundantly demonstrate that drainage and sewerage are essential elements of health in populous districts. Independently

of actual loss of life which so frequently attends their neglect, impaired mental or bodily vigor, arising from the influence of defective drainage and sewerage, reduces daily in thousands of cases the capabilities of individuals to such an extent, that it may be considered equivalent to a loss of income by the deterioration or diminution it induces in the effective services which each can give to his occupation. Calculated as a matter of profit and loss, everything indicates that the expense required in establishing proper measures to avoid these evils would be far below the loss consequent upon the inefficient arrangement too frequently witnessed at present.

Notwithstanding it would seem, as above, that an ample array of facts exist for the determination of the immediate removal, at almost any expense, of the house refuse of populous cities, yet a wide difference obtains as to what constitutes a proper or timely attention to this important matter; and the method and means which we propose to apply are by no means as yet universally accepted as the proper ones.

Some twenty years since, the author adapted the "water carriage" system of sewerage as in his opinion the most suitable to our needs, disregarding wholly the consideration of thereby rendering the utilization of the sewage for agricultural purposes still more expensive than it then promised to be, and in fact rendering it a matter of very questionable economy; and in support of these views, a late writer of eminence* sums up a most exhaustive treatise on the subject in the following terms:

"Having reviewed the most important methods that

* "Digest of Facts relating to the Treatment and Utilization of Sewage," by W. H. Corfield, M.A. M.B., Professor of Hygiene and Public Health at University College, London. 1871.

have been practiced for the removal of refuse matters from towns, we have been led to adopt the following definite principle: That the method which does, in practice, where it is anything like efficiently carried out, remove at once and completely from the vicinity of habitations the various sorts of refuse in the most expeditious manner, is the one which must be the most conducive to health.

"We have pointed out that the principle of all dry methods of excremental removal, without exception, is to leave the excremental matters in and about the house for a certain time—so long, in fact, as they do not become an absolute nuisance. We maintain that this is essentially wrong in principle, and we point in support of our opinion to the facts with regard to the state of the health of the inhabitants of midden-closet towns.

"As to the dry earth system, its principle is the same, though its action is more thorough. Although it has been shown to have a great advantage where it has replaced midden heaps and cesspools, we maintain with Dr. Rolleston and with Dr. Parkes, that it has not been shown that the compost is disinfected as well as deodorized. And until this is proved to be the case, it is safer to resort even to the offensive pail system, where excrement cannot be allowed to remain within dwellings for any length of time, on account of the great nuisance that would be caused by it, than to a plan which destroys the warning, but is not proved to have removed at the same time the danger.

"It has at various times been proposed to deodorize coal-gas; the result of this would certainly be that accidents by poisoning and by explosion would be increased to an enormous extent. We know that the poisonous ingredient *par excellence* of coal-gas—the carbonic oxide—is perfectly inodorous; we know also that the emanations which pro-

duce typhoid fever are not offensive or disagreeable to the smell; and it is a *presumption*, as Dr. Parkes says, to suppose that all danger of their production is removed by mixing excrement with earth. But even were this presumption to become a demonstrated fact, the greatest objection to the earth system (one which is essential to it because it is a dry system) would still be as strong as ever, viz.: that whenever the earth supplied happened to be in too small quantity, too moist, or of bad quality, or the air to be very damp, or the compost wetted through carelessness or otherwise, the danger of infection would at once arise. How frequently one or more of these conditions would be fulfilled need hardly be pointed out.

"Miss Nightingale well says, in her remarks on the *Progress Reports* in the Indian Sanitary Report (1870, p. 45): 'The true key to sanitary progress in cities is water supply and sewerage. No city can be purified sufficiently by mere hand-labor in fetching and carrying.' As civilization has advanced, people have always enlisted natural forces or machinery to supplant hand-labor, as being much less costly and greatly more efficient.

"We turn, then, to review briefly the results already attained by the water-carriage system, despite all the disadvantages of it (when badly carried out). We know what it has done; we know that in the towns where it has been introduced in conjunction with other sanitary improvements, it has been the means of practically annihilating cholera; we know that it has been very little less effectual in the extermination of typhoid fever. We are sure that it is the speedy removal of the refuse matters that has accomplished this, because, in towns where free exit has not been allowed for the sewage from the sewers, the death-rate of typhoid fever has only very slightly diminished, or has slightly

increased, or even (in one case) has very considerably increased. Such cases, although deplorable in themselves, are instructive to the sanitarian in pointing out beyond question of a doubt that it is especially the improved sewerage arrangements that have effected these results. We have seen, too, that by the construction of deep drain-sewers * the mortality from phthisis has been diminished to a very remarkable extent, amounting in one case to nearly half the former number of deaths.

"And although we have, for a multiplicity of reasons, felt ourselves justified in condemning the drain-sewer system, we have certainly to thank it for the discovery of the all-important fact that one of the most potent causes of phthisis is a water-logged subsoil; so that while we advocate impervious pipe sewers, we must also insist that towns shall be provided with deep subsoil drains. Not only this, but we have also seen that these special improvements have been accompanied by the still more important one of a reduction in the general death-rate, amounting to about a fifth part of the previous number of deaths in nine out of the twenty-five towns reported on by Dr. Buchanan.

"Having then the sewage to deal with, the first object must be to get rid of it in an unobjectionable manner, and the next to utilize it if possible. Plenty of evidence has been given to show that it must not be sent into the rivers, as has heretofore been almost invariably done; and that it is only a little less objectionable to resort to this plan after a preliminary straining off of the suspended matters. We have, however, seen that by intermittent downward filtration through soil (and perhaps, where convenient, through ashes, etc.), sewage can be adequately purified, so that the

* By drain-sewers are meant sewers which, in addition to the ordinary run of the sewage, lead off subsoil water.

effluent water may be turned into a stream; by this plan, however, the manure which is so much wanted is almost entirely lost, the greater part of it escaping in solution in the effluent water in the form of nitrates and nitrites.

"As to the utilization of sewage, we have shown the futility of all attempts at precipitation of its valuable constituents; in fact, 'it is hopeless,' as Dr. Hewlett says, 'by either one or any of these operations to render the effluent water anything else than sewage.'

"Finally, with regard to irrigation farming, the facts that we have brought together seem to us to show clearly that it satisfies the three conditions which we have laid down; the sewage is purified, a profitable agricultural return is ensured, and the health of the neighborhood is not endangered.

"We are, then, reduced to the following simple issue: wherever it is possible, irrigation should be carried out, the sewage having been previously freed, by one or other of the methods described, from the offensive suspended matters, which must be deodorized to prevent the production of a serious nuisance. Wherever, on the other hand, irrigation is practically impossible, intermittent downward filtration, through soil or other suitable material, afford the means of satisfactorily purifying the sewage."

We have been led to extract thus copiously from a standard authority on the subject of the disposal of sewage, from the fact that, in view of the difficulty of compelling the ordinary occupants of tenement houses to make a proper use of water-closets, and the ill effects resulting from this neglect, members of boards of health of undoubted intelligence, in some of our cities, have been found, notwithstanding all the advantages of the water-carriage system, to recommend the substitution of some form of cess-

pool for such localities, to be cleansed by the local authorities periodically. The evidence above given should be regarded as conclusive, that relief from the evils of neglect in crowded tenements should be sought in some other direction than the abolition of the water-carriage system.

It is to be presumed that the defects in the form and dimensions of drains and sewers which existed until within the last thirty years, are well known. That their dimensions were so far in excess of what was required, as to preclude their contents from being swept out by currents of water, and hence that cleansing by manual labor was under the then existing state of things a necessity. They were at best but "elongated cesspools" for the retention and storage of whatever was thrown into them, and the evils resulting from this state of things brought about an examination into the causes which had led to them, and the result was not only that their dimensions were found to be defective, but their shapes were equally in violation of the known laws governing the movement of fluids, and hence that their design and construction, to be efficient, should be confided to a different class of men from such as had hitherto controlled them—in a word, instead of this being left to the ordinary builder, who regarded the subject as one demanding no further attention than to insure sufficiently large channels for the reception of whatever it was desirable to conceal from the sight of dwellers above ground, it was, under a more enlightened view of sanitary needs, confided to the skilled intelligence of the hydraulic engineer. All this, copiously illustrated, will be found in the various reports of sanitary commissions appointed by the British government to inquire into means for the improvement of the health of towns, commencing with the first report in 1847, and extending to the present

time; and the General Board of Health Reports, commencing in 1852, also presented to Parliament, as well as the various commissions of later date, as the "Pollution of Rivers" and kindred subjects. These reports constitute the mine from whence was abstracted the first elements of our subsequent progress in sanitary art in this country, and have been so repeatedly drawn upon, as scarcely to yield anything new at this date. Instead, therefore, of dwelling upon what *was*—we shall confine ourselves to what *is*, and what *should be*, under the light afforded by the experience of many years of practice.

GENERAL CONSIDERATIONS.

In devising a system of sewerage for a populous district, there are several controlling circumstances to be taken into consideration. It would appear, at first sight, that the first thing to be considered would be the population of the locality. Were the sewers to be confined to the withdrawal of sewage proper from the vicinity of dwellings, this would to a great extent be the case, but even then the extent of the water supply would be a preponderating element in the calculation. If, for instance, the water supply were derived from wells on or near the premises as in country villages, the amount of sewage would be materially reduced from what might be anticipated were the water for domestic use obtained by the simple act of turning a faucet; and whether the supply of water was intermittent or constant, would exercise an important influence on the amount of consumption or waste from dwellings.

The sewage from a dwelling differs by an insignificant amount in bulk from the water consumed or wasted. In fact, the water taken into a dwelling for all purposes, is the measure of the sewage which leaves it; and a generous

water supply, such as is found in most of our cities supplied by water-works, would, under proper management, suffice to carry off all excrementitious or human refuse. But with the sewers confined to this purpose, an additional system of drains on a grander scale is called for, to remove the storm-waters which would otherwise flood the premises, and prove the cause not only of present injury and discomfort to the inhabitants, but subsequently objectionable as well on sanitary grounds. If the double system of conduits referred to are recommended, as they have been, on the score of preserving the rainfall uncontaminated with house-sewage, with a view to its ultimate use as a feeder to the streams to be utilized for domestic purposes, which is the strongest plea which can be offered for the increased expense attending a double system of drains—this, and the increased commercial value of the house sewage undiluted by rainfall—it can be answered that the rainfall collected in the gutters of a city, charged, as it frequently is, with atmospheric and other impurities, differs on analysis in no essential from house-sewage. This has been tested time and again in English towns and cities, and the commercial value of the house-sewage of cities as a fertilizer of crops has no such value as should induce any special complication in its collection and preservation; while the increased cost and complication growing out of these additional drains for surface water, which lessen in no degree the further necessity for subsoil drains, are far beyond any of the presumed benefits to be derived from them.

The modern system of sewage contemplates the construction of a system of impermeable conduits, which, with the water supply to dwellings, and at times the rainfall on the surface, shall prove adequate to the prompt removal

from the sites of human habitation, and before time shall be afforded to set up any dangerous fermentation, all excretæ and refuse from human, animal, or vegetable life—everything, in fact, putresible to be found in the vicinity of dwellings—to some outlets, to be further dealt with by natural or artificial means in order that they may not prove a source of mischief to the residents of other localities. This method is known as the "water-carriage system"; and as the solid fæces adds no appreciable amount to the bulk of the house-sewage, so the house-sewage calls for no appreciable increase in the capacity of the sewer to carry it off, beyond such as is necessary for the accommodation of that amount of the storm-waters as modern improvements in habitations requires to be carried off in a definite time. This eliminates the consideration of the extent of the population on an area to be drained, and leaves the dimensions of the sewers to be controlled measurably by consideration of the character and extent of that area. Closely-built and paved districts will affect the result only so far as contributing the proportion of the rainfall due to its area in less time after its fall than that from suburban districts. The further consideration of this in its bearing on the dimensions of sewers will be noted subsequently.

The points which demand our attention may be stated as follows:

First. The area and physical outlines and controlling features of the district to be drained; its geological character, and the depth to which it may be desirable that the drainage should extend.

Second. The rainfall in the district, with consideration of the maximum fall of rain in a given interval of time, and the proportion of such storm-waters as it is proposed to carry off by the sewers.

THIRD. The character and extent of the water supply.
FOURTH. The final disposal of the sewage.

THE PHYSICAL OUTLINE OF THE DISTRICT AND THE DEPTH OF THE DRAINAGE.

The physical character of the district to be drained is of the first consequence. In the case of a city or town, the valleys of the streams or natural valleys of drainage will more or less influence the direction and grades of the streets to be opened. If the town occupies say the summit and slopes of elevated ground, the problem of drainage is presented in its simplest form. The accumulation of sewage from the dwellings, the surface and the subsoil waters, are led, following the line of streets, to their natural outfalls without the boundaries of the district; and if the latter be in a running stream of any volume, or in tide-water, the immediate removal of the waters and sewage from the vicinity is secured.

If the district to be drained is in general level, but intersected by valleys of depression merely, with accompanying elevations, but without any decided valleys of drainage, and the springs which crop out are fed from a distant source from beyond the boundaries of the district, the difficulties and expense of drainage and sewerage are much increased. If in the vicinity of running streams or tide-water, which will be at a lower level, the direction of the main trunk of discharge must be selected with a view to their construction to the lowest point of outfall, independently of the grade of the streets; and either by tunnels or deep excavations, artificial drainage outfalls must be established to which all lines of drainage are tributary.

If the site to be drained is depressed below the general level of the country, or but slightly above the level of the

water-courses or tide-water, the difficulties in the way of thorough drainage are still further enhanced, and recourse must be had to pumping from reservoirs or tanks, which are located at the lowest points so as to form receptacles into which the sewage is received.

It is rarely that the town site to be drained will be found to conform entirely to any one of these cases, but in many instances will be found to comprise some of the peculiarities of each, in which case the plan must be modified to suit the circumstance of each sub-district, as they may be called, and each will require its special treatment.

The principle of interception, though applicable in many cases where the extent of surface-draining to a single outfall is large, is peculiarly so where the sewage collected in a low level requires to be raised by pumping in order to secure an outfall. In this case, all the drainage from the upper portion of the district may be led away to a natural outfall, leaving only the portion below that level to be collected in reservoirs to be dealt with by machinery. In the late sewer works of London, the principle of interception is well illustrated, where, instead of hampering the sewers of the low districts with all the sewage from the higher levels, the latter is drained off directly by its own sewers, and the sewage from the low levels alone is lifted by pumping machinery into the higher level sewers, thus giving it the necessary fall to the outlet. (See Intercepting Sewers, London Main Drainage Works, Appendix.)

The character of the geological formation has a bearing chiefly upon the extent to which the subsoil may be drained. If the entire district is city area built up and paved, the amount of rainfall reaching the subsoil will be comparatively insignificant and need not be regarded; but if, owing to the formation, the subsoil be fed by springs from sub-

urban districts, special provision must be made for its drainage, otherwise the soil will become water-logged in the lower districts, and the effect upon the health of the inhabitants will be very marked.

The effects of a dry subsoil in its influence on the health of residents has been frequently noted, and a greater number of deaths from phthisical diseases is seen where the inhabitants are located upon a retentive geological formation than takes place when they are disposed on a pervious formation; and it has been observed that districts having a rapidly inclined retentive formation have a less death-rate from phthisical diseases than those in which the same formation is comparatively flat. Wherever the tide ebbs and flows in the subsoil at a certain distance below the surface, it does not appear to be injurious to health unless some other circumstances tend to complicate its action. Nor is a subsoil charged with fresh water injurious to health, providing motion be secured in the water by a fall to the outlet of the water-bearing strata; but stagnant water is the enemy of life, and must be removed by drains or drain-sewers in order to the public health.

Whatever relation the site of a town may have to the surrounding country, it is obviously desirable that the drainage from these outlying districts should not be permitted to permeate the subsoil of the town itself. If it cannot be led directly to a more natural outlet, a system of catch-water drains should be established to intercept so much of it as would otherwise find its way into the subsoil of the town, and conduct it by suitable channels to the streams or drainage valleys, where its appearance would lead to some provision being made for its harmless disposal.

The principle of the water-carriage system, as previously remarked, consists in the building of impermeable sewers

or conduits so arranged as to remove the surface rainfall and the water supply which is discharged to waste from the dwellings; and they should be so thoroughly constructed that the sewage shall in no case be allowed to leak from the sewer to poison the subsoil, but all the liquid being retained in the sewer, it is made the instrument in scouring from the latter, all solid matters and offensive substances of whatever kind which may have gained access to them.

Although the drainage of the subsoil forms no part of the duty of the sewers proper, but is to be provided for by sewer drains, it is undeniable that, notwithstanding all efforts to the contrary, the so-called impermeable sewers do to a certain extent drain the subsoil from subsoil waters. In some cases to a large extent, but more or less so in all; but we cannot believe with a late writer, that this is owing largely to the imperfect joints of the pipe-sewers and the pervious character of the brick itself, and that such sewers become in consequence proper subsoil drains. If such were the case, their efficiency as such would depend upon the head of the subsoil water being always greater than that of the sewage; but this cannot be depended upon by any means, and a leak in one direction may be followed by a leak in the other, when the consequences would be precisely that of the old-fashioned drains, the inefficiency of which as sewers, by allowing the liquid to percolate through, and retaining the solids, led to the adoption of the more perfect impermeable sewers of later days.

There is no difficulty whatever in rendering a brick or pipe sewer water-tight, *as it should be*, if it be desirable to avoid deposit of sewage within it, and the trench will still permit a withdrawal of the subsoil water without any further provision for it, providing it be not encountered in too great volume. But if springs of water occur in the

sewer-trench, provision must be made for their removal, which will be noticed under the head of Foundations.

If subterranean reservoirs of water exist by reason of the impervious character of the strata, they must be dealt with in the same way, the outlying drainage having been intercepted and led off as previously suggested. The varying character of the formation will call for the exercise of the judgment of the engineer as to how far he may rely upon the sewer-trench alone as a subsoil drain.

In determining the depths to which the houses are to be drained, much diversity of practice obtains in different localities. In the city of Brooklyn the depth of the bottom of pipe-sewers, or the laterals below the level of the streets, is in general twelve feet. The lateral sewers being placed at one foot above the bottom of the mains, make the latter thirteen feet in general below the street level. This provides for a basement below the level of the street of $9\frac{1}{2}$ feet in height, or a basement story extending two feet below the street level, with a cellar of $7\frac{1}{2}$ feet, as follows:

Basement or cellar below street level	9′.6″
Cellar floor and covering of drain	1′.6″
Drain	6″
Fall of drain 2″ in 10′ for 50 feet	10″
Fall to main sewer 2″ in 10′ for 30 feet	6″
	12′.10″

Custom in neighboring localities, or the presumed wants of the inhabitants, however, will control these dimensions.

If property owners see fit to construct a sub-basement still lower, which is not unfrequently done in warehouses, its drainage must be obtained by mechanical means and at private expense. The public authorities do not undertake to drain, in general, lower than as above indicated, although it is true the sewers are at various depths, reaching to forty feet below the street. When the fall to the outlet will per-

mit the depth of twelve feet it should be had, and if the character of the house foundations require especial precautions of draining, even a greater depth should be given; but this, like many of the requirements of drainage, must yield more or less to local circumstances. If the basement or cellar floors be below the level of tide-water, they cannot be effectively drained, even though the foundation walls and floor be rendered absolutely water-tight; no system of valves heretofore in use to this end can be depended upon as self-acting. Self-acting valves or flaps both of iron and burnt clay have been used, hung with shackels, and to a certain extent have proved successful; but valves of this description are liable to obstructions from the presence of heavy bodies in the sewage becoming fixed under the flap, and cannot be regarded as efficient in all cases.

With reference to the level of the outfall, as bearing upon the depths to which the drainage may be carried—supposing the rise and fall of tide to be about five feet; all sewers of large dimensions of outfall—that is to say, all over four feet in diameter—may be located with their inverts one foot above low tide level. The large sewers having generally a small fall, the rise of the tide backs up more or less, and the large body of water on the ebb tide has a good scouring effect on the contents of the sewers. It is desirable, however, when the main sewer at the outfall is of small capacity, that its invert should be at a higher level than is required in the case of large sewers, even to placing the crown of the arch at or above high water, to insure as far as possible the sewers of such limited dimensions from being tide-locked at every rise of the tide.

In the event of storms of rain occurring at the time of high water, the smaller sewers have not the capacity requisite for retaining the surplus storm-waters during the rise of the tide,

and the consequence is that at such times there is no escape for the drainage from the houses, and the pipes of the house connections are subject to pressure, which find relief in the failure of the joints of the drains and the flooding of the premises.

The residents on a line of sewer having paid their tax for the improvement, expect to be benefited by it; and that they shall not be disappointed in this very natural expectation, the outlet of their sewer should not be sealed by the tide, unless the sewer above the outlet be of large capacity and good inclination; hence the depth of drainage near the shore line will be correspondingly diminished, dependent upon the range of the tide. Great disappointment obtains at times on this account, and complaints arise in some instances that cellars are flooded after the construction of drainage works which had never previously been liable to such accident. From a mistaken view of the purpose to be secured by a proper system of drainage, the tendency appears to be constantly towards placing the outlets of sewers at too low a level, and the only defect in the system of sewerage in the city of Brooklyn grows out of the mistaken effort to drain below the tide-level, and the consequent sealing of the outlets of some of the sewers by the high tides which usually accompany severe storms.

OF THE RAINFALL AND THE PROPORTION TO BE PROVIDED FOR IN THE SEWERS.

If the rain which falls upon the streets and open areas of cities and towns could be excluded from the sewers entirely, the self-cleansing process would be much facilitated; that is to say, the supply of water for domestic purposes in all cities where the water supply is provided by the authorities, or furnished by large companies (in this

county ranging from fifty to one hundred gallons daily per capita) is sufficient (a proper regard being had to size, shape and inclination of the channels of discharge) to carry off all refuse from the dwellings, and render the sewers themselves entirely self-cleansing, save in localities but little built upon and unpaved, and near the summits of very flat gradients, where the volume of waste water has necessarily slight scouring power.

The expense of a double system of pipes has tended to throw upon the sewers the double duty of sewers and drains for surface water, and this latter service is still further complicated, by the necessity which it involves of being the vehicle for removing much of the street refuse, sand, gravel, lime, building materials, and whatever incumbrances the streets of a city under a lax system of street cleaning accumulate; for with all care possible, these substances, so far from being deposited by the rain-water, as theory indicates it should be, in the street basins built for that purpose at the corners of the streets, they are in truth swept into the sewers, and in such quantities as to prove a fruitful source of expense in preserving them free from obstructions to their flow, and this under the penalty of a complete stoppage and consequent hazard to the public health.

The increased dimensions of the sewers rendered necessary to meet this additional demand upon their carrying power, is itself an element in diminishing the value of the sewers as a self-cleansing channel of discharge for sewage under the ordinary conditions of its flow. An efficient system of street cleaning in paved cities could be devised whereby the evils attendant upon the present practice might be essentially mitigated, and it would be found but little more expensive to keep improper substances out of the sewers than to clean the sewers, outfalls and street-basins

by hand. The custom being pretty well established, however, of passing the storm-waters which fall upon the district into the sewers (or rather so much of it as can be made to enter them through the street-basins at the corners of the streets) charged with the street refuse, the consideration of the maximum rainfall becomes important in determining their dimensions, and, as will be shown, if the dimensions of the sewers meet this latter requirement of the storm-waters, nothing further need be sought in this direction.

Except under the tropics, the average amount of excessive rains which fall in a unit of time, is not subject to so great variation in different localities as is the total yearly fall. Localities with annual rainfalls varying from twenty-four to one hundred inches, yet present but little difference in the maximum amount which falls in a given time, say a quarter of an hour, or possibly longer; hence, for the purpose of providing for removing this storm-water, we have less to do with the yearly rains than with the maximum rainfall in short intervals of time; and a more important element still is the duration of these excessive rains. A rainfall at the rate of two inches in the hour continuing for half an hour, which is almost unprecedented in this latitude, would not prove nearly so difficult to deal with as would a storm yielding less rain, but extended over a greater interval, and this arises from the manner in which the mains are fed; those laterals which empty into the mains near the outlet, discharging all their water before the arrival of that from the upper levels of the district.

In 1856, when the author was projecting the sewer system of the city of Brooklyn, the yearly observation of the rain-gauge had been recorded in that vicinity for thirty years previously in a public institution, but the records of the amount or duration of special storms were very meagre; in

fact, the only accessible continuous record of any value was that of Dr. Minor of Brooklyn, extending from the year 1849, or but seven entire years. The yearly average for the entire series of thirty years was 42.68 inches; the maximum fall in any one year (1830) having been 53.47; and the minimum (1845) having been 32.14; while for the eight years from and including 1849 to 1856, it had averaged 44.25 inches, or nearly two inches in excess of the general average for the longer term, while the individual storms were as follows: Of the rain storms, or rather rainy days, there were but nineteen in which the rainfall in *four* hours was an inch or over, and but fifteen days in which the rainfall for the entire twenty-four hours was as much as two inches, and the heaviest storms recorded are two of $2\frac{1}{2}$ inches of rain in *four* hours; and notwithstanding the fact that the average yearly rains for the time under observation had exceeded by a very striking difference the yearly average for thirty years past, yet no such a recorded occurrence had taken place as a rainfall of one inch within an hour.

And hence we concluded, that if provision were made to carry off one inch of rain falling in an hour, it would suffice; for although greater storms than this might be anticipated, yet their occurrence would be at such long intervals that the damage done would be comparatively insignificant.*

Since that day, and in other localities, records of storms have appeared, and more attention is now paid to this

* "No system of sewage yet proposed in any city contemplates the removal of *excessive* storm-waters by means of the sewers alone—such storms, for instance, as discharge for short intervals two or three inches of rain in the hour. These occur at long intervals, and are of short duration, and the damage is usually confined to limited areas; whilst the construction of sewers to meet the contingency would be attended with an enormous expense over the whole city, both in construction and repair, and prove of doubtful efficiency when suddenly called upon, and extremely objectionable as conduits for the ordinary flow of sewage."—*Report of the Engineer to Commissioners of Drainage, Brooklyn*, 1859.

branch of meteorology and to the publication of the records. In Mr. J. H. Shedd's interesting report on the sewers of Providence, 1874, will be found some valuable statistics of rainfall in that locality, from which it appears that of 185 storms recorded for the twenty-six years previous to 1860, the rate of fall per hour is as follows:

131	storms	rainfall at the rate of	0.25	inch per hour	or less.
18	"	"	0.33	"	"
9	"	"	0.40	"	"
7	"	"	0.50	"	"
8	"	"	0.62	"	"
3	"	"	0.67	"	"
3	"	"	0.75	"	"
4	"	"	0.87	"	"
1	"	"	1.00	"	"
1	"	"	1.75	"	"
185					

But as illustrating the importance of more extended observations in a branch of science of which we as yet possess too little material with which to found any reliable theory for practical application, we quote from the same report in continuation as follows:

In fourteen years to the 1st of January, 1876, the time of rainfall is recorded in 139 storms as follows:

In 98	storms	at the rate of	0.25	inch per hour	or less.
9	"	"	0.33	"	"
2	"	"	0.40	"	"
10	"	"	0.50	"	"
5	"	"	0.60	"	"
3	"	"	0.70	"	"
2	"	"	0.80	"	"
1	"	"	0.90	"	"
1	"	"	1.00	"	"
1	"	"	1.12	"	"
1	"	"	1.20	"	"
1	"	"	1.40	"	"
1	"	"	1.52	"	"
1	"	"	1.83	"	"
1	"	"	2.00	"	"
1	"	"	2.32	"	"
1	"	"	3.15	"	"
139					

Making nine storms in fourteen years against two in the previous twenty-six years. The amount of these excessive rains will vary in different localities.

And the proportion of the rainfall which we may estimate as reaching the outlet of the sewers in a given time and which will control their dimensions, as might be expected will also vary very materially under the different circumstances of the case. The character of the surface, whether paved or otherwise—the proportion of the surface which is built upon or covered—the relative compactness of the dwellings and the extent of yards and gardens—the inclination or grade of the streets, as also of the sewers—the evaporation from covered surfaces, and the absorption of the soil and the geological formation upon which it rests, —all these will influence more or less the quantity of water which a given rainfall in the district may be expected to discharge at the outlet.

The gauging of sewers during and after heavy rains necessary to the determination of this question have never been undertaken, so far as we are aware, in this country, save on a limited scale.* The amount of water which finally reaches the sewers from a given rainfall has, it is true, been frequently observed, and is found to vary materially in the same district; but to determine the proper capacity of the sewers, the ratio of the time occupied in the discharge of the storm-waters, to the duration of the storm itself, is more important to be determined than is the percentage of the rainfall which finally reaches the sewers. But a limited number of these observations have been recorded save as

* The only storm-gaugings of any extent which are reliable, and we are not aware that these have ever appeared in print, were conducted in London by Mr. Wm. Haywood, Engineer to the Commissioners of Sewers, when the main drainage works of London were in contemplation, the plans for which on the north side were prepared by him and Mr. Frank Foster.

below noted, and none of them indicate so short a time for the discharge as *twice* the duration of the storm, but, on the contrary, always exceed it even three, four and five times, and frequently still more. In the case of a storm of rain continuing for several days, this could not happen; but if the intervals of time were closely observed wherein the rain falls at a less rate than one inch to the hour, the aggregate of these intervals would much exceed that of the times wherein the rain was in excess of that rate.

The circumstances which control the amount of rainfall which would reach a sewer outlet during the continuance of a rain-storm, must be dependent on many local considerations, which it would seem would entirely preclude the idea of estimating its amount in one locality by the experience acquired in another, yet the necessity for determining this amount before the construction of the sewers of a city is so important, that we were led to take the results of the gaugings made during a series of years by Mr. Wm. Hayward, Engineer to the Metropolitan Board of Works, London, as in all probability applicable to the drainage of city areas in general, unless the features of the locality, or the duration of individual storms, differed very widely from what had been observed by him.

The conclusion to which we then arrived was, that no rains of sufficient magnitude to swell the discharges of the sewers to any extent, ever occupied one-half the time in falling which they did in discharging at the outlet; and hence, that to construct the sewers of dimensions calculated for a greater discharge than one-half the rainfall in the time occupied by its fall was a needless expenditure. And nothing observed since has tended to weaken that opinion.

Of course, open fields and unbuilt districts would tend to retard the delivery of the rainfall into the sewers, and

thus render a smaller capacity permissible; yet it would be erring on the safe side to accept the results obtained of the discharge on city areas to govern in the dimensions of sewers in suburban districts.

With reference to greater rainfalls, such as at the *rate* of two inches and over to the hour, we have noticed that such a rate of fall is for very limited lengths of time, and very rarely (and within our own observation never) continued for a full hour.

Mr. Shedd's Table (Report of 1874) gives a rain in September, 1862, of two inches for an entire hour; and again in June, 1870, of 3.15 inches in an hour; and again in June, 1873, of 2⅛ inches in an hour. The area covered by such storms we cannot but think must have been very limited, more like water-spouts indeed, and possibly of but few acres in extent; but, however this may be, the infrequency of such storms of rain (but thrice in forty-one years) renders any provision for carrying them off by subterranean conduits wholly uncalled for, and, indeed, if such were not the case, it would be out of the question to attempt it, owing to the great expense of maintenance as well as construction of such works.

The comparative frequency of an inch rain in an hour—that is to say, its frequency when compared with such falls as two and three inches in the same time—renders its consideration a more practical question, and the possibility of this *rate* of fall occurring for shorter intervals of time is so apparent from past observations on the sea-board, and in fact in the interior of the country, that we may regard it as a very proper maximum to be considered in designing sewers for city drainage. It has been adopted in England as such, and, so far as we can learn, also in this country.

It is desirable to keep the cross dimension of sewers as

small as possible, and this not in view merely of diminished expense of construction, but for their increased efficiency when the flow through them is reduced to the dry weather discharge or the water-supply merely; but the suffering and ill-health consequent on inundated cellars among the poorer classes in our cities, owing to deficient drainage facilities growing out of restricted dimensions of sewers, should present an argument in favor of providing for a liberal estimate in the capacity of sewers.

WATER-SUPPLY.

Whatever water is supplied to a dwelling leaves it as sewage. And whenever the term sewage is used it is to be so understood; although the actual amount of sewage proper, or animal excreta, forms but a small part of its bulk. It is of interest to know the relative amounts of human excreta furnished by the population, but its chemical constituents is of less moment in this connection, and may be left for other hands to elucidate. The proportions and ingredients must vary somewhat, but it has been shown* that the excrement from individuals varies in its amount according to the sex and ages of the individual, and that in a city of 100,000 inhabitants, there may be estimated 37,610 men, 34,630 women, 14,060 boys, and 13,700 girls, and the yearly weight of their excreta, liquid and solid, may be represented as follows in pounds avoirdupois:

	Fæces, pounds.	Urine, pounds.	Total.
37,610 men.....	4,521,664	45,217,760	49,739,424
34,630 women.....	1,237,040	37,467,592	38,704,632
14,060 boys.....	1,239,504	2,423,648	3,663,152
13,700 girls.....	274,736	9,541,344	9,816,080

* First Report of Rivers Pollution Commission to Parliament, London, 1870, —from the Researches of Wolf and Lehman.

It appears from the preceding, that the house-sewage may be averaged as over 1000 pounds yearly per inhabitant, and in bulk about 120 gallons, or 16 cubic feet yearly, or .044 of a cubic foot daily, while the house consumption of water for all purposes may be stated at an average of about 20 gallons per head, or 2.66 cubic feet, or 60 times the bulk of the human sewage; together 2.7 cubic feet. But this does not represent the city sewage which is passed off by the sewers. The refuse from manufactories, markets, slaughter-houses, stables, laundries, baths, and animal refuse of all kinds, is estimated in cities as in the aggregate differing but little in bulk from the human sewage.

In the water supply of a city, the consumption is, for convenience, estimated per capita of the entire population; and when thus estimated as sixty gallons, about two-thirds of this amount may be taken to represent the sewage from the houses and out-buildings, the remaining one-third of the water-supply to the city being absorbed in the extinguishment of fires, street and garden washers, fountains, flushing of hydrants water-pipes and sewers, street-sprinkling and building purposes, leakage of water-pipes, and in some localities shipping uses—all, with the exception of the last two items, reaching the sewers directly through the street openings; and notwithstanding it would seem that the sewage proper is so diluted by from sixty to one hundred volumes or even more of water, and so less virulent as a poison, yet analysis shows to the contrary, and even with the further addition of storm-waters, the discharge at the outlet is still *sewage*. The rain acts as a means of purifying the air, cleansing the roof and streets, and a great amount of gaseous and other impurities is thus gathered up and enriches the contents of the sewers, which would otherwise remain to the discomfort of the inhabitants.

The bulk of sewage thus generated in the twenty-four hours, experience has shown is not delivered from the sewers with any regularity, but about one-half of it is discharged in from six to eight hours of the twenty-four, the variations depending upon the character and habits of the population, a marked peculiarity in this respect characterizing the discharge from the different districts of a city. If we estimate one-half of the bulk of sewage flowing in twenty-four hours as discharged in eight hours, it will be a safe estimate in our cities; so that, with a water-supply of sixty gallons per head, if one-half of this or four cubic feet is discharged in eight hours, it will give one-half a cubic foot per hour as the maximum discharge of sewage from all sources per head of the population. A modern block of sixteen houses occupies with the street about one and a quarter acres, and with say ten residents in a house, would give eighty cubic feet of sewage-discharge per hour per acre; but, as will be seen subsequently, the sewers should be designed to carry off a rainfall of one-half inch in depth over the same area in the same time, or 1815 cubic feet per hour per acre. We thus see, that if the sewers are designed in view of the requirements of this proportion of the storm-waters, no further regard need be had to the bulk of the sewage or water-supply. It must be remembered, however, that while the sewers are designed to carry off the rainfall without running full bore, and with capacity for the maximum sewage-discharge at the same time, they are, by fulfilling these requirements, rendered of such dimensions as to materially affect their fitness as channels of discharge for house-sewage alone; and this constitutes the greatest difficulty in sewering cities, the reconciliation of these conflicting necessities to such an extent as shall not jeopardize the successful operation of either alone.

THE FINAL DISPOSAL OF THE SEWAGE.

This subject has been a fruitful source of embarrassment in all localities not situated directly upon the sea; more particularly of inland manufacturing towns, where the pollution of the waters by sewage and refuse has entailed disease, or threatened it, in localities where the water-supply has been derived from a lower level on these contaminated streams.

In England, where the spread of manufactures and the natural growth of the population in limited areas has pressed the subject upon the attention of the people, the authorities have instituted most exhaustive investigations into the principles which underlie the whole subject, and much conflicting testimony has been elicited, and professional men of the first eminence, whose opinions it would be presumed would be taken without a question on matters appertaining to their profession, have been found in direct opposition to each other on the apparently simple question—whether sewage could by any treatment short of its destruction prove other than sewage?

The necessity for utilizing city sewage for agricultural purposes does not at present exist, nor will it probably for some time to come, in this country of wide areas and cheap farming lands. The consideration of the disposal of it without injury to the rights of others has begun, however, to be regarded as a necessity in some localities; but the importance of the subject, and the experience of other countries in exhibiting the dangers of delay in properly treating it, has not impressed itself upon the public mind to the degree which we must expect before our national and state governments shall establish bureaus for the systematic collection and dissemination of sanitary statistics. Massachusetts has

well led the way, however, and the annual reports of the board of health of that State, extending from the year 1871, are most valuable additions to our stock of knowledge on sanitary matters in general. With the exception of several of our State governments, where nominal boards of health exist by act of legislature, private associations and local or municipal boards of health are the only organizations at present interested in this subject, and both the pecuniary means for extended observation and investigation, as well as a proper combination of effort, have hitherto been wanting, which has very much tended to circumscribe the field of research and limit the dissemination of the knowledge acquired. While we are writing, the proceedings in Congress indicate some movement in this direction, by the formation of a National Board of Health, and if its *personnel* can be separated from political interference, it will be a great step taken in the right direction.

The British government have for many years past had commissions composed of her most eminent scientists engaged on this subject—such as the Sewage Commission appointed in 1865—"to inquire into the best mode of distributing the sewage of towns, and applying it to beneficial and profitable use." The Rivers Pollution Commission appointed in 1867 to inquire "how far the present use of rivers for carrying off the sewage of towns and populous places, etc., can be prevented without risk to public health, and how far such sewage can be utilized." And the Royal Sanitary Commission appointed in 1868 "to inquire into and report on the operation of the sanitary laws of towns, villages and rural districts in Great Britain and Ireland, so far as these laws apply to sewage, drainage, water-supply, removal of refuse, etc., and other conditions conducive to public health." The health of towns commissions, and

various other commissions, all reporting to Parliament, and either they or their successors are still actively engaged in this work, and issuing reports which are of great value to us —indeed, most of our information on the subject of utilization of city sewage will be found in these publications.

The field is a wide one, and, as may be supposed, the prospect of pecuniary gain has brought many schemes before the public, which a short experience has shown to be without substantial merit. On a small scale and under favorable circumstances, some have given the promise of success, which a more extended trial has shown to be fallacious. It would appear, however, that these efforts have been kept alive by the recognition of the well-known fact, based upon chemical laws, that the wastes of animal life form the sustenance of vegetable life, which in its turn remolds the elements into new shapes for animal uses, and as an aid to nature in carrying out her economical transformations; any other view of the treatment of sewage has been regarded as unscientific and wasteful.

The principle would appear to be sound, but in crowded areas like great cities may it not be, that the scale upon which operations must of necessity be conducted in order to the rapid relief called for by sanitary needs, involve so great expenditures, and under any circumstance is attended with the liability of developing so much that is offensive to the senses, if not detrimental to health, that it becomes questionable whether in such localities the preparation of the sewage in order to fit it for agricultural uses, should be regarded as of the first importance; whether, in a word, we had not better waste it as we best may, and consider its value as so much expended towards insuring the public health? regarding anything expended in promoting an improvement in the condition of life and health as infinitely

more than an equivalent for its money value? And, indeed, it is evident, that while we may assign a money value to the ingredients of city sewage, the circumstances under which that sewage, in view of the promotion of the public health, is necessarily delivered for manipulation, are such as to render the expense of arriving at its fertilizing ingredients in a form fitted for anything but a limited local use, beyond their value to the agriculturist.

In this view of the case, our only care should be to provide the means for the most immediate and thorough removal from the sites of human dwellings of all refuse matter liable to affect the health of the inhabitants. But there is one point which deserves consideration in this disposal of the sewage, if in sufficient volume to pollute the streams in its neighborhood to such a degree as to render them unfit for domestic use—that is, some method of rendering it innocuous, and thus not to throw upon others what the first consideration of health demands that we should rid ourselves.

Some of the methods proposed for the purification of sewage might prove advantageous, providing, however, that instead of aiming to utilize it so far as to render the product commercially valuable to the agriculturist, and so render the undertaking a paying one on the investment, the effort be confined to the purification of the streams, even at a pecuniary loss to the town or village undertaking the work.

There is no doubt whatever, that a proper chemical treatment of sewage will clarify and purify it to a certain extent. But here the question of cost comes in, and it will appear that no known method of treatment exists by which we can manufacture manure from the material discharged at the outlets of city sewers at a profit to the city,

but must pay for getting rid of our refuse, just as for any other necessary of life.

If this is the result reached in the older and more densely populated countries, where the value of land for tillage is so much greater than in this country, we can scarcely anticipate that the scheme for utilizing sewage will be likely to prove successful here. An examination, however briefly, of the merits of the various processes which have been proposed, having in view the utilization of the sewage of cities, would swell this volume needlessly, and it will suffice to name some of the more prominent methods of procedure.

The several methods divide themselves under two heads —the natural and the artificial. The first embraces the methods of filtration and irrigation. By filtration is meant the appropriation of a given area of ground, over which the sewage, in the condition in which it leaves the sewers, is poured from pipes, either by means of pumps or otherwise as the locality may render necessary, and allowed to percolate through a certain distance or depth, dependent upon the nature of the soil; the solids, which may remain on the surface, being removed for agricultural uses, and the liquids carried off by artificially arranged underground drains, and discharged into the water-courses. When the power of filtration ceases by reason of the soil becoming clogged, another piece of ground is appropriated in the same way, and the first allowed to recover its original condition by the action of the elements, as it best may.

By the method of irrigation, the sewage is led to the farm by pipes and distributed over the land to be fertilized, upon which crops have been planted.

The artificial methods are either mechanical, or of a more complex chemical nature, or a combination of both.

The mechanical embraces the method of separating the solids and fluids by means of screens and filters, variously arranged, or by patented expedients called "extractors." The chemical or precipitation processes are very numerous.

There is, first, The lime process; That by means of tanks and the use of a preparation of alum; The lime and chloride of iron process; Scott's process by the use of lime and clay; The crude sulphate of alumina, or Bird's process; And the phospho-alumina process of Forbes and Price. Holden's process, or sulphate of iron, lime, and coal-dust; The Blythe or superphosphate of magnesia process; Slathert's process, or the use of sulphate of alumina, sulphate of zinc, and fine charcoal; The A. B. C. process, so called from the initials of the ingredients used, viz., alum, blood, and charcoal; The peat and filtration process; The dry earth system; The midden-plan filtration through charcoal and cinders, known as Weaver's process; and many others of less note, not to mention the cesspools, "fosse mobiles," pails, boxes, tubs, etc., all largely used in Europe.

As before remarked, the consideration in this place of the arguments for or against any of these plans, with the conflicting evidence of their trials and experiments, would be a waste of space. The curious in such matters are referred to the Second Parliamentary Report of the Sewage Commission, London, 1861, and to the Seventh Annual Report of the State Board of Health of Massachusetts for 1876, and to the digest referred to in a foot-note on page 12. None of the patented processes need occupy our attention any further. Their true bearing upon the subject-matter in hand having been succinctly stated in the extract quoted on page 12 of the Introduction; and as illustrative of the method of irrigation therein recommended as the only known mode whereby city sewage could be efficiently

utilized, and the complications attending its use under even favorable circumstances, we quote briefly from a Report by the late J. P. Kirkwood, which will be found at length in the Massachusetts Board of Health Report referred to above.

There are two kinds of irrigation:—The irrigation which, whether using water or sewage, applies it to the crops only as required, and in quantities calculated to produce the best results. This kind of irrigation may be said to be always profitable; but in this case, what is not wanted for the crops is not purified, and the surplus of that which has been used is not purified, although it has been somewhat deprived of its noxious qualities.

The other kind of irrigation is that which has in view not merely the utilization, but also the absolute purification of sewage water. In this case there will be, first, such a liberal extent of land provided as will admit of the sewage during the growing season, at least, being entirely used by the different crops arranged to that end. The process of irrigation to produce the best results being always intermittent, the grounds are broken up into many divisions or plots (the circumstances prescribing their size and number), so that the sewage fluids can be transferred at will from one plot to another, or from one kind of crop to another; and there would want to be some idle plots, so to say, upon which the sewage could be thrown at seasons when it was in excess of what the growing or maturing crops required.

The reader will understand that in the process of irrigation a certain portion of the fluid will settle into the ground; and it is desirable that the ground should be of such a free and open character as to admit of this and to encourage it; for it is this earthy filtration supplementing the action of roots of the growing crops which deprives the sewage of its noxious qualities, and renders what is left of it fit to escape

into the neighboring brook or stream. If this character of ground is not present, if the irrigation field has a heavy or clayey soil, deep drainage will enable it to produce the same cleansing effects; but the ground must be high enough to admit of this drainage-water, thus purified, escaping freely into some neighboring stream.

To this, the most favorable view of irrigation as a means of entire purification, there are two exceptions, and under a negligent manipulation of the process there would be more; these are, first, the storm-waters, which at certain times will make the delivery through the sewers so large as to render any reasonable extent of irrigation-fields incompetent for the time being to meet the excess, which cannot be allowed to flood the field, but must be otherwise taken care of; the second exception is the winter, when for some months, it may be, the irrigation-fields will become useless as such. It will be thought by some that in the winter the sewer-fluids might be passed into the stream without rendering its waters so objectionable as in summer; but the reverse is said to be the case: the gases which escape from the sewer-deposits in summer from over the entire surface of the stream are sealed up in winter, so that by breaking a hole in the ice the bad odor is made perceptible by this kind of concentration in winter, when in summer the sense of smell does not reach it under ordinary circumstances. The winter-water is therefore more dangerous than the summer-water, except that, there being generally more water flowing in the river then, the poisonous fluids entering it will be more diluted.

It is probably true that no process or combination of processes for the sufficient purification of sewage-waters has ever produced results which collectively made it remunerative; the precipitate collected by most of the patent pro-

cesses will always sell for something for farming purposes, and where irrigation is used besides, crops will be large and have commanded good prices, but the adjuncts (whether of land for filtration or otherwise) necessary to destroy the whole of the filth, more than eat up the profits. It is a great advantage and encouragement to be able to reduce the cost of this kind of purification; but to attain the desired result without any outlay, far less to make it a means of profit, is not, in the present state of our knowledge, to be expected.

CHAPTER II.

PREPARATION OF SEWERAGE PLANS.

THE area to be drained will of course be mapped to scale, showing the streets, avenues, and artificial features of the district, with the levels above some standard base, marked at the intersections of streets and governing points, noting all water-courses and springs, and the levels of their varying flow of dry weather and storm-waters, and all gas or water pipes and substructures of all kinds. If on the banks of a river, or tide-water, the levels of high and low water, of ordinary and spring tides with the direction and velocity of the currents and prevailing winds, and if areas not included in the scheme of the works, are yet naturally drained through the district under consideration, their position and character will be embraced in the plan.

Contour-lines will be drawn through the points of equal elevation throughout the plan, thus representing the features of the surface by a system of horizontal curves. From a consideration of these, having in view the direction and relative importance of the streets and avenues, the natural outlets for drainage and the general direction of the mains, will be apparent at a glance. Local circumstances, such as existing or projected improvements, or the location of deep re-enterings in the shore-line, or shallow bays, may forbid the adaption of the natural outfall to some portion of the district, when the circumstances attending the change of such outfall to a more desirable locality will be duly con-

sidered, and the selection of the proper outfall be made. Recollecting that no sewage, or discharge into the sewer, is to be allowed to stagnate, but such inclination and direction is to be given to the main as will remove the sewage by the force of the waste-water supply from the immediate vicinity of the dwellings, and to this end, in some cases, such as on the banks of a rapid stream, or near tide-water, it may be advisable, instead of leading the sewage by long lines to a single outfall, to divide the drainage into sub-districts of a more limited area and quicker discharge.

In localities on tide-water, or when the flood tide may be expected to bring back the sewage discharged at other states of the tide, it may become expedient to concentrate the flow to a single outfall, removed beyond the influence of the flood tide, which could not be effected possibly by dividing the discharge into several outfalls.

In any event, and however limited the area which it is proposed to drain in the first instance, the general plan of the whole district which admits of drainage by the same outfalls, should be carefully made and filed for future reference, and, if possible, be made a legal instrument, that should control future local improvements, and not permit so important a matter as the public health to be made secondary to any other interests.

Having the general plan of the district to be drained, the next step will be to divide this area into sub-districts which contribute their quota of discharge to the main outfall, or to independent outfalls, as the requirements of the case may call for, and the areas discharging into these several sewers determined on and recorded on the general plan, when the inclination, dimensions and characteristics in detail of the several works will come up for consideration; and the first is the capacity of the mains.

The principles involved in this, embrace a few of the simplest elementary laws of hydraulics; and to meet contingencies growing out of varying circumstances impossible otherwise to provide for, such a margin must be given to the determination of dimensions and capacity of the works, as to render unnecessary all investigation into the precise value to be assigned to almost infinitesimal factors, applicable with manifest propriety to the calculations of the discharge of pipes for water-supply under pressure. No sewers should be projected with the design of running them under a head. The character of the materials mostly used in their construction forbids this, except in extreme cases requiring special attention, to be noted subsequently.

Simplicity of design is a first requisite in all the appendages connected with works of sewerage—largely rendered necessary from the imperfect police in our cities, and the neglect which follows in the maintenance and operation of these works, which, removed mostly from sight, are left very much to take care of themselves, except at times when the natural result of such neglect makes itself known to other senses than that of sight.

Before submitting a formula for the section of main sewers, the fact that the received hydraulic formula for the discharge of water in pipes under pressure, the result of theoretical deduction from experiments, are not strictly applicable to the circumstances attending the discharge of city sewers, calls for some notice.

In the disposal of the storm-waters from the roofs and gardens of city dwellings, the first increments from the fall of rain at or near the head of the system of branch sewers which supply the mains, enter these branches in limited quantities, but with a high velocity; if direct from the roofs through the house leaders with a fall of 50 or 60 feet, and

if from the yards and streets, with a fall of 10 or 12 feet, in a distance of about 20 feet. The velocity (it may be near 30 feet per second) is diminished by the changes of direction which the water undergoes before reaching the drain or sewer, but enters the latter with a decided velocity. The branch-sewers are rarely if ever filled in districts near the summits, but as the stream advances it receives new increments, moving under the same circumstances of limited volume and high velocity, and the aggregation of these supplies gives a velocity to the waters in the sewer greater than what would be due solely to the slope or inclination of the sewers themselves.

The retardation due the movement of water in channels, in few cases, in branch sewers, equals the velocity induced by the above circumstances attending the method of supply; hence, instead of an equilibrium being established between the opposing forces, and a uniform velocity obtaining, there exists an acceleration of current, extending to the junction of the branch with the main. These branches each bring their contributions, gathered in their respective districts, under similar circumstances with the above; if with a greater velocity than that existing in the main, an additional force is thereby imparted to the movement in the main, and in any event bringing an additional volume of water, which, not finding immediate escape, acquires an additional head, and an acceleration is the result, which does not meet with sufficient resistance to become a uniform current until after the large volumes added by these various branches cease, or after the junction of the last branch of any magnitude. In the above we have had regard to the action of storm-waters in closely-built districts and properly arranged sewers or drains, where the waters are collected in small threads, gradually accumulating, and the mains are

increased in capacity until they terminate at the outlet with an increased head.

In the movement of water from a reservoir, on the contrary, or under a constant head, the circumstances are entirely different; the water commences its movement by filling the pipe near the head, and thence running under pressure, and the capacity of the mains grows gradually less until they finally ramify into the small service-pipe with diminished head. The velocity in the main near the reservoir increasing for a limited distance by the effect of gravity or the inclination of the pipe, and subsequently of the slope of the surface of the running stream, until the increased velocity develops an increased resistance from friction, and an equilibrium becomes established between these opposing forces, when the water then assumes a uniform velocity.

When this uniform velocity obtains, the pipe is not necessarily running with a full bore, but space exists for an additional amount of water, which, if introduced by branch pipes, would give a total of discharge at the outlet in excess of what entered at the head. We thus see that hydraulic formula, based upon experiments on the motion of water in pipes supplied wholly from a single source at the head, cannot properly be taken to represent the discharge of city sewers receiving large increments from various sources between the head of the system and the outlet.

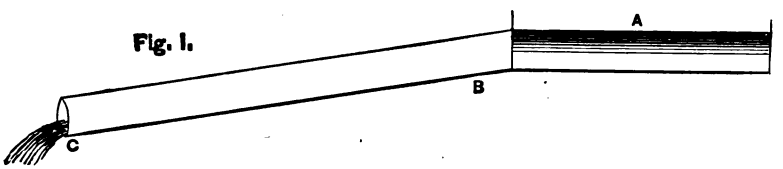


Fig. 1.

To illustrate this, take a reservoir *A*, Fig. 1. From this reservoir let the pipe *B* lead, discharging the water from *A* at a lower level *C*, the resistance of entrance into the pipe

B being overcome by the bell-mouthed shape of the entrance; the flow of water from *A* thus filling the pipe *B* at its upper end, the level of water in *A* remaining constant and without current.

These are the conditions under which experiments to determine the flow of water in pipes under pressure were conducted, and form the basis of all of our hydraulic formula; and have been repeated from time to time with increasing care and attention to the varying elements tending to produce error in the results, until they have reached a very high degree of accuracy—leaving little, indeed, to be desired in that respect.

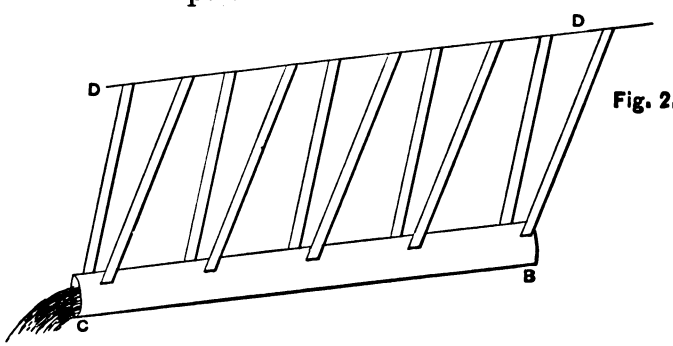


Fig. 2.

Take now the same pipe *B*, Fig. 2, but instead of feeding it from a reservoir at *A*, let the water of the reservoir be considerably elevated above the pipe, as at *D*, the flow into the pipe *B* being fed by means of smaller pipes at frequent intervals on the line of its entire length. Will any one maintain that the discharge of water in a given time will be the same in both cases, or that the same capacity of main pipe is required in either case? In the first case, as is well known, while the same amount of water in a given instant must flow out at the outlet *C* as entered at *B*, yet the volumes for any unit in length of the pipe is diminished as it proceeds, and does not fill the bore of the pipe towards the end of a long

pipe, and the velocity within the pipe must increase in precisely the same ratio as the decrease in volume. But in the second case, the greater velocity in the branches by reason of their greater head and the augmentation of the volume of water by the discharges from these constantly multiplying sources, the sectional area of which amounts in the aggregate to very many times the entire area of the main pipe, results in a greater discharge in a given time from the outlet *C* than if the whole had entered through the head at *A*. Again—

If the pipe *B C*, Fig. 2, represents a long line of sewers receiving its supply from innumerable branches from roofs and streets, a heavy rainfall may be supposed to deliver simultaneously its waters into the sewer for its entire length; of course the water from the lower branches reaches the main opposite them as soon as that from the higher branches reach the sewer, but if the descent of the main be uniform, the water from the lower branches will have partially run off before that from the upper appears at the same place—and yet it has been customary to estimate the required size of the sewers as of such dimensions as would discharge the entire rainfall (diminished by evaporation and absorption) did it enter at the head alone! and the characteristics of the sewers were determined by reference to tables of velocities under given rates of inclination, etc., upon this supposition; whereas the unknown quantity is the size of the sewer under known conditions; and these latter are, the distance to the point of discharge (which is fixed), as is also the inclination, by means of the grades of the streets occupied by the sewer, and the quantity of rainfall to be carried off in a given time, the velocity, as shown above, not being attainable by a consideration of the inclination alone.

The preparation of a simple formula expressive of the diameter of a sewer under the given conditions, is all we need

for the determination of the dimensions of sewers for populous districts. Commencing with the first recognized principles of hydraulics, we shall briefly exhibit them in proper form, and thence deduce the generally-received formula for motion of water in pipes or channels, and from the results of experience modifying this to suit the new relations of sewer discharge, arrive at a general formula (empirical) which is suited to all conditions of rainfall and discharge of sewers.

In the movement of water in channels of any kind, the threads or lamina of water near the sides or bottom are retarded in velocity in proportion to their proximity to the latter. The *rationale* of the process has not been definitely determined, but we find that the resistance to motion is directly proportioned to the extent of rubbing surface or the wetted perimeter of the channel, and inversely proportioned to the area of section having that wet perimeter. Considering the sectional area of the channel-way as representing for a unit of length the volume of water, and calling it S, and representing the length of the wet perimeter of this section by P, the resistance to motion is found to be proportional to $\frac{P}{S}$, and also *approximately* to the square of its velocity (the wet perimeter being supposed constant), and hence may be represented by $v^2 \times \frac{P}{S}$ into some coefficient to be determined by experiment; calling this coefficient c, the expression will be, $v^2 \times \frac{P}{S} \times c$.

In the movement of water down any incline, it obeys the same laws under the action of gravity as other bodies, the accelerating force being represented by the sine of the inclination of the slope, or $\frac{\text{the height}}{\text{the length}}$ into the measure of

the force of gravity,* or $\frac{H}{L} \times g$, and the resistance as before being $v^2 \frac{P}{S} c$, these two expressions must be equal in the case of a *uniform velocity*, or when the retardation and acceleration become equal,

$$\frac{H}{L} g = v^2 \frac{P}{S} c, \text{ or } \frac{H}{L} = \frac{c}{g} \times \frac{P}{S} \times v^2 = \frac{HgS}{LcP} = v^2 \text{ and}$$

$$v = \left(\frac{HgS}{LcP}\right)^{\frac{1}{2}}.$$

This is the original formula for velocity of water running in channels in feet per second—adopted more than a century since. Simple in its deduction from known physical laws, but rendered somewhat more complicated by the various values assigned to the coefficient c,† as determined by various experimenters, under necessarily different circumstances and facilities for accurate observation; but, on the whole, the differences for any practical purposes are but slight.

Taking $\frac{H}{L} = \frac{c}{g} \times \frac{P}{S} \times v^2$, and putting c' for the constant $\frac{c}{g}$, we have $c' = \frac{H}{L} \times \frac{S}{P} \times \frac{1}{v^2}$, and substituting for c' a value .0001 derived from experiments, we have $\frac{1}{c'} = 10{,}000$, and solving for v, we have

$$v = \sqrt{\frac{H}{L} \times \frac{S}{P} \times 10000} = 100 \sqrt{\frac{H}{L} \times \frac{S}{P}} \quad . \quad . \quad \text{(Eq. 1)}$$

* g, or the force of gravity, may be taken at 32.16 feet, but more accurately from the formula $g = 32.1695\ (1 - .00284\ cos.\ L) \left(1 - \frac{2h}{R}\right)$, h = the elevation of the stations above tide, and R = the radius of the earth at tide-level at the station, all in feet.—*Rankine.* For Table illustrative, see Appendix.

† In Downing's Hydraulics, several experiences are cited confirming the general value for c, or the coefficient of friction so-called. The value given to this coefficient, however, is as diverse as the experimenters who have been engaged in it; and from a number of them of equal authority, we select one that is simple, admits of ready application, and an experience of over twenty years confirms as sufficiently reliable.

$\frac{S}{P}$ being the sectional area of the water divided by the wet perimeter, or what is known as the *hydraulic mean depth* (H_y); the greater its value the less the relative resistance of the channel-way to the volume of water moving through it.

In the case of circular pipes running full, D representing the diameter of the pipe in feet,

$$\therefore \quad \frac{S}{P} = \frac{D^2 \times .7854}{D \times 3.1416} = \frac{D}{4},$$

or H_y = *one-fourth the diameter of the pipe.*

The formula would then become for pipes flowing full,

$$\text{velocity} \quad v = 100\sqrt{\frac{H}{L} \times \frac{D}{4}} = 50\sqrt{\frac{H}{L} \times D} \quad . \quad . \quad \text{(Eq. 2)}$$

in feet per second. For the discharge Q in cubic feet per second, multiply the area of the pipe by the velocity, and

$$Q = .7854D^2 \times 50\sqrt{\frac{H}{L} \times D} = 39.27\sqrt{\frac{H}{L} \times D^5},$$

in cubic feet per second,

$$\text{or per minute,} \qquad Q = 2356\sqrt{\frac{H}{L} \times D^5}.$$

This is the formula used by Beardmore in calculating his hydraulic tables.* From Equation (2) all the formula in use for pipes under pressure may be derived, varying merely the forms of expression and changing the constants to suit more modern experiments.

The experiments conducted under the auspices of the French government by M. Darcy are now, thanks to the labors of Mr. Francis of Lowell, accepted in this country as the most reliable; and the formula derived from them for the flow of water in pipes, leaves nothing to be desired in point of accuracy.† For velocity in feet per second, his formula is

* These tables are much to be recommended for office use in facilitating calculations connected with water-works and water-supply.

† On the extension of the Glasgow water-works, the engineer found the dis.

$$v = \sqrt{\frac{d^2 H}{.00371\,(d+1)\,L}}$$

all the dimensions being in feet except diameter of pipe d, which is in inches. The numerical factor in the denominator is for new and clean pipe, which in the case of pipes much encrusted with tubercles varies as high as .0082. This formula gives more accurate results than equation (2), and is to be recommended for use in computations for pure water-discharge; but minute accuracy is less important in this connection than simplicity of application, especially as with whatever accuracy a formula may represent a water-discharge under pressure, it must, as we have seen, be sensibly modified to suit the purpose of sewage-discharge under the circumstances previously explained.

To illustrate this, take the equation (2), which represents mean and uniform velocity in feet per second—all measures in feet:

$$v = 50\sqrt{\frac{H}{L}D},$$

and as the cubic feet discharged per second divided by the area of the pipe will equal the velocity per second, then if Q be taken to represent cubic feet per second,

$$\frac{Q}{.7854D^2} = 50\sqrt{\frac{H}{L}D}, \qquad Q = 39.27D^2\sqrt{\frac{H}{L}D},$$

$$Q^2 = 1542D^5\frac{H}{L},$$

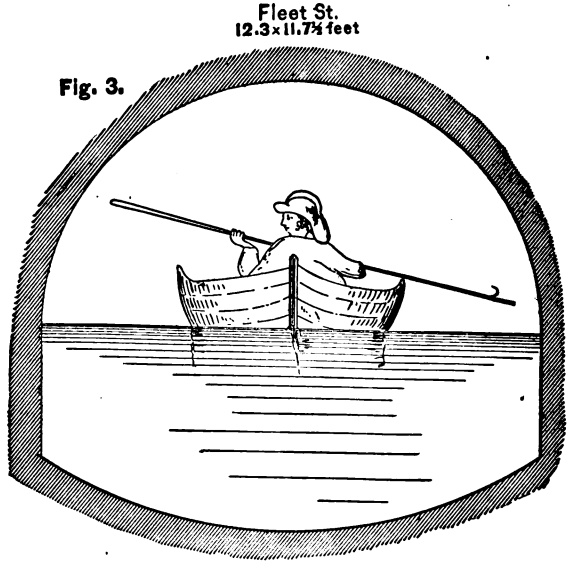
$$D = \sqrt[5]{\frac{Q^2 L}{1542H}} = \text{diameter of pipe in feet.} \quad . \quad . \quad (3)$$

An inch of rainfall in an hour is 3630 cubic feet per acre, and if we estimate one-half of this as running off in an hour,

charge of the four-feet main of coated cast-iron pipe to be in excess of the flow as originally estimated by Weisbach's formula, but agreed almost exactly with the result as derived from Darcy's formula, confirming the value of the latter for water-pipes of any dimension. See Appendix for Tables from Darcy's formula.

then 1815 cubic feet per hour = .5 cubic feet per second per acre; or one-half the number of acres to be drained would represent the cubic feet per second to be discharged. Performing the calculation with the rate of inclination of $\frac{1}{480}$, that is, $\frac{H}{L} = \frac{1}{480}$, and we find that D, or the diameter of the circular conduit required to carry off this amount of water falling on 3000 acres, would be nearly 15 feet!

Fig. 3.

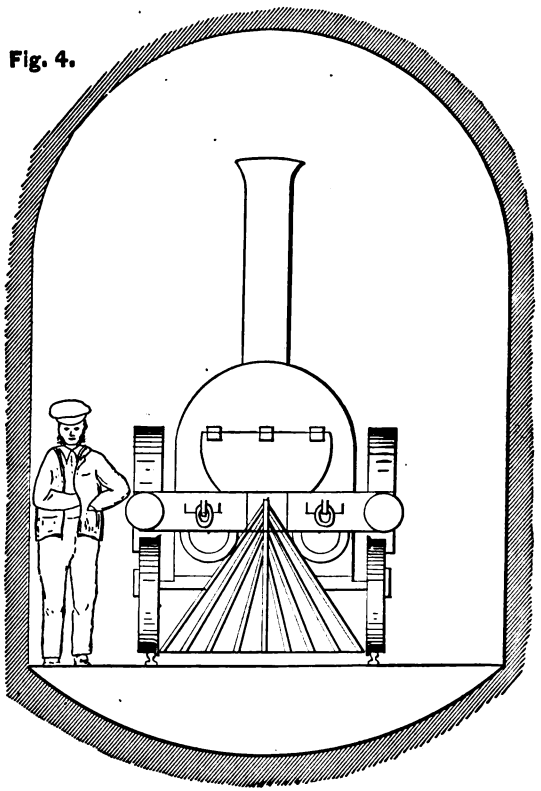


The Fleet Street sewer, London, drained 4400 acres, and was at the outlet 12 feet into 18½ feet, and at the boundary of the city, 11½ × 12¼ feet. To give an idea of what these dimensions mean, we append two sections of this sewer drawn to scale—Fig. 3 and Fig. 4. We cannot say that this sewer was designed on the received hydraulic formula for discharge of water from a reservoir, but we believe it to have been, and we know that many of the difficulties which the early sanitarians had to contend with, grew out of the presumed necessity for these enormous dimensions in main

sewers. It is clearly seen by existing sewers draining more extended areas, and at a less inclination, that no such dimensions are necessary.

The truth of the fundamental equation for the velocity

Fig. 4.



18.6 x 12 feet
Old Fleet St. Sewer

in pipes under pressure, it will be perceived, is based upon an equilibrium being established between the accelerating force of gravity and the retardation occasioned by the resulting increase of velocity, and only professes to be correct after the velocity becomes *uniform*, which, as we have seen in the case of sewers discharging from constantly-increasing

sources, with equally high heads, can never obtain; and did the storm-waters from the upper branches commence with a full volume and head, and continually receiving additions in both respects, make a common discharge at the outlet, the resulting velocity would in many cases be something alarming. But in the case of a sewer draining extended built up areas this can never happen. The discharge from the lower districts, having a shorter distance to run and with an equal head, will discharge a large portion of its storm-waters in advance of that from above.

Take a case in actual practice. A sewer drains 869 acres, 122 of which is rural and without buildings; the remainder is well built up, and some of it densely so. All except some 20 or 30 acres is graded and paved. The fall of the main at the outlet, and for nearly a mile, is at the rate of $\frac{1}{1135}$. With an inch of rain within the hour by Hawksly's formula (p. 61), the dimensions of this sewer should be equal to that of a circle of six feet diameter, and it is so built. It has repeatedly run full, and owing to bad curves in the line a mile and a half from the outlet, has been gorged to overflowing. The contributions to this sewer extend to the very outlet, where it is densely built up. If an inch rain in an hour were calculated over the entire area as delivered in two hours, it would give 435 cubic feet per second. This divided by the sectional area of the sewer, or 28.27 square feet, gives a velocity per second of 15.38 linear feet, which, according to Du Buat, would suffice to move angular rocks! and yet there is no indication of any such action—in other words, there is no such velocity.

Therefore either one of two things must exist; either the sewers are not called upon to deliver proportionally so much of the rainfall in a given time as has been assumed, or the discharge from the lower branches is greatly in ad-

vance of that from above—both of which we have reason to believe is the true state of the case. Hence, for the dimension of sewers, we cannot assume a mean velocity for the entire length of the sewer,* *a priori*, based upon the rate of fall and diameter, nor upon observations made at the outlet. The quantity of water entering at the different branches will, from the varying character of the district to be drained, be so various in amounts and velocity, that to attempt to express these relations in a general equation for the entire district, would be subversive of the principle of simplicity to which we aim, and prove too complicated for any practical purpose. We are debarred, therefore, by the above consideration, from attempting to compute the sizes of sewers for draining extended areas of storm-waters, by assuming a given uniform velocity of discharge; and in looking for some clue to the proper solution of the question, were led to adopt an extremely simple expression, which had been extensively used elsewhere with good results.

In the elaborate report of the late Mr. J. P. Kirkwood on the water-works and sewers of Brooklyn, published by Van Nostrand in 1867, it is stated that the formula used in designing the Brooklyn system of sewers was one by Sir Joseph Bazelgette, which, arranged logarithmically for use, is as follows: $\frac{3\ log.\ A + N + 6.8}{10} = log.$ diameter in inches of main, discharging the rain from one inch of rain per hour; A being acres drained, N the length in which the main falls one foot. This formula was used by Sir Joseph Bazelgette and Mr. Wm. Haywood in the plans for the intercepting and main drainage works of London, but, as we are informed by Mr. Haywood, was prepared by Thos. Hawksly, Presi-

* Where the expression "length of the sewer" occurs, it refers, of course, only to the length of main which is uniform in section.

dent of the Institution of Civil Engineers, an engineer, as he expresses it, "of high scientific ability, and, perhaps, practically and theoretically, our most eminent hydraulician, and one who has had more practice in the construction of water-works than any other in our country."

The formula noticed above is more simple in its use than the one which we propose; but while for the smaller dimensions of sewers and for limited areas it gives ample capacity, it did not prove so satisfactory in the larger; and, as will be seen by the following table, where the comparison is instituted between it and the formula which we propose, the latter, while giving slightly less results in the smaller areas, gives the increased dimensions in the larger, which experience has pointed out as desirable in this locality.

TABLE SHOWING COMPARATIVE DIAMETERS OF CIRCULAR SEWERS IN INCHES, BY MR. THOS. HAWKSLY'S FORMULA (P. 61), AND FROM EQUATION (4), TO DRAIN THE RAINFALL FROM ONE INCH OF RAIN IN AN HOUR, ON THE UNDERMENTIONED AREAS OF URBAN TERRITORY.

Acres drained.....	43	75	135	308	630	1117	1925	3025
Fall $\frac{1}{480}$ or 11′ per mile.								
Hawksly.....inches.	27.4	32.4	38.6	49.5	61.3	72.9	85.8	98.2
Proposed..... "	27.6	33.1	40 2	52.9	67.2	81.3	97.4	113.3
Acres.....	50	87	155	355	735	1318	2225	3500
Fall $\frac{1}{250}$ or 21′ per mile.								
Hawksly.....inches.	26.8	31.6	37.6	48.2	60.	71.4	83.6	95.8
Proposed..... "	25.7	31.	37.5	49.5	63.	76.5	91.1	106.
Acres.....	63	113	203	460	950	1692	2875	4500
Fall $\frac{1}{160}$ or 33′ per mile.								
Hawksly.....inches.	27.5	32.8	39.1	50.	62.2	73.9	86.7	99.2
Proposed..... "	26.	31.5	38.3	50.4	64.2	77.8	92.8	108.
Acres.....	78	143	257	590	1200	2180	3700	5825
Fall $\frac{1}{125}$ or 44′ per mile.								
Hawksly.....inches.	28.5	34.2	40.8	52.4	64.8	77.5	90.9	104.1
Proposed..... "	26.6	32.5	39.6	52.2	66.1	80.7	96.2	112.
Acres.....	90	165	295	670	1385	2486	4225	6625
Fall $\frac{1}{80}$ or 68′ per mile.								
Hawksly.....inches.	28.6	34.3	40.8	52.2	65.	77.4	90.8	103.9
Proposed..... .. "	26.	31.9	38.7	50.9	64.3	78.8	94.	109.
Acres.....	115	182	318	730	1500	2675	4550	7125
Fall $\frac{1}{60}$ or 88′ per mile.								
Hawksly.....inches.	29.9	34.3	40.6	52.1	64.7	76.9	90.2	103.2
Proposed..... "	27.	31.4	37.8	49.9	63.5	77.	91.8	107.

Taking the equation (3) the origin of which we have pointed out, and changing the exponent from 5 to 6, we have

$$D = \sqrt[6]{\frac{Q^2 L}{1542\, H}} \quad . \quad . \quad . \quad . \quad . \quad (4),$$

an empirical formula by which the dimensions corresponding to "Proposed," in the above table, are calculated, and which is the formula we would recommend for use for outfalls of sewers, and which will be found, if intelligently used, sufficiently accurate for all purposes of sewer discharges for populous districts.

Previous to illustrating the method of using this formula, we would observe, in reference to the extent of areas to be drained, that it is not desirable, nor necessary under a proper arrangement of outfalls, that a single service* main should be called upon to discharge the rainfall from such extended city areas as were embraced in the old Fleet Street sewer, such for instance as an area of 4400 acres or 7 square miles, and the reason for this will be shown in the operation of the sewers. On pages 36–7, it will be seen that city territory as ordinarily built up and supplied with water at the rate of sixty gallons per inhabitant, will yield to the sewers about .022 cubic feet per second per acre during the time of maximum flow, but the capacity of the sewers is designed to carry off .5 cubic feet per second per acre, or twenty-three times more than the water-supply, and of the bulk of the latter, not more than $\frac{1}{60}$ is human sewage; hence, in seasons of drought, the proportion of sewage is so relatively small compared to the dimensions of the sewer as to facilitate the deposition of offensive matter by reason of the small scouring power of the current at such seasons;

* By service, we mean a main receiving house-drainage, as distinguished from an intercepting sewer.

and the engineer, by a careful study of the grades, and by introducing the principle of interception so happily illustrated in the new drainage works of London, can usually without difficulty so far restrict the drainage areas as to leave not more than 3 square miles, or 3½ at the utmost, to be drained by a single main. But in this, as in many other points, the engineer must be governed by the necessities of the locality under treatment.

An extended area divides itself into sub-districts, each with its main sewer. In determining the areas of these sub-districts, regard should be had to the nature of the surface, whether likely to be built upon, or to remain sub-urban, and a corresponding reduction should be made in the latter case, of the rainfall likely to reach the sewer within the prescribed time. But this reduction should be made with extreme caution. In this country it is sometimes so doubtful what direction city improvements may take, that sewers projected in view of draining city property alone, and proportioned accordingly, are extended to take in property not originally presumed to be built upon; and while it remains in such condition, the comparative slowness with which its waters reach the sewers, permits of their efficient drainage in storms, notwithstanding that such drainage formed no part of the original scheme for which the sewer was designed: but after building and paving this area, the increased rapidity with which it will discharge its waters into the sewers, may result in gorging them, and possibly flooding a portion of the district.

We will show first the method of application to this formula of the rains and rates of rainfall. Upon the supposition that the rainfall of one inch is carried off in twice the length of time of its fall, one-half the number of acres drained will represent the quantity (Q) in cubic feet per second, or

one-half inch per hour of rain equals .5 of a cubic foot per second per acre. For an inch per hour of rain, the discharge will be represented in acres by substituting for Q (in equation 4), $\frac{A}{2}$; and for two inches of rain per hour, $Q = \frac{A}{1.33}$, upon the supposition that for the latter .75 cubic feet per second per acre must be provided for; and for intermediate rainfalls, the factor to be substituted would be proportional, as for 1½ inch rain it would be $Q = \frac{A}{1.65}$. Resuming the consideration of the one inch rain per hour, which, as we have shown, we would recommend as meeting all the requirements likely to arise in this latitude, we have, by substituting for Q in equation (4) its value in acres, or $Q = \frac{A}{2}$; then $D = \sqrt[6]{\frac{A^2 L}{6168 H}}$. Let $N = \frac{L}{H}$, or the length in feet in which the sewer falls one foot, then $D = \sqrt[6]{\frac{A^2 N}{6168}}$; D representing the diameter of the sewer in feet.

Representing this logarithmically for convenience of calculation, and we have

$$log.\ D = \frac{2\ log.\ A + log.\ N - 3.79}{6} \quad . \quad . \quad . \quad (5)$$

A = acres to be drained in one hour of one half the rain falling in the same time, or ½ inch in depth of rain for a rainfall of 1 inch.

N = length in feet in which the sewer falls 1 foot.

D = diameter in feet of the outfall of the sewer.

Substituting in equation (4) for Q the value $\frac{A}{1.65}$, or $\frac{A}{1.33}$, and reducing in the same manner, we will have the equa-

tions expressive of the diameters to carry off the proper proportions of the rainfall of 1½ inches and of 2 inches respectively in an hour. These equations are so far general that, having determined the amount in cubic feet which it is desirable to drain off per second per acre, they become applicable to all areas and rates of inclination for the respective rainfalls.

The dimensions of the main outfall which receives the drainage of the entire district having been thus determined, the dimensions of the first branch-sewer draining a sub-district embracing a definite portion of the first is next computed in the same manner, and so on until all the branch sewers which make up the discharge of the main, with their respective and varying rates of inclination, have had their dimensions duly determined.

The small areas which in each sub-district make up the bulk of the drainage, such, for instance, as blocks to the extent of one or two acres, which on a computation would give a smaller sewer than 12 inches diameter, yet should be provided with a 12″ pipe, as the least size admissible for *street* drainage, but little economy would result from adopting anything of less dimensions, and the liability to obstructions peculiar to such localities is thereby sensibly diminished by the use of the larger pipe.

Except under peculiar circumstances, where tunneling becomes necessary, or the line of the sewer, for some proper purpose, takes a direction from necessity not in precise accord with its natural line of drainage, the grade of the sewers will follow in general a *line parallel* with the street grades, or the differences will be slight; hence, it is not in general practicable to fix the fall of the sewers by any presumed necessity of rendering them self-cleansing.

In the matter of self-cleansing sewers, it is not a given

fall which will render a sewer self-cleansing, although it is frequently so assumed, but it is a certain velocity in the flow; and sewers of different sizes and rates of inclination may give the same velocity. For example, using the hydraulic formula of pipes under pressure (Eq. 2), a circular sewer of 10 feet diameter, having a fall of 2 feet per mile or $\frac{1}{2640}$, would have a velocity of 3 feet per second. A sewer of 5 feet diameter with fall of 4′ per mile $= \frac{1}{1320} = 3$ feet per second. A sewer of 2 feet diameter with fall of 10′ per mile $= \frac{1}{528} = 3$ feet per second. A sewer of 1 foot diameter with fall of 20′ per mile $= \frac{1}{264} = 3$ feet per second. All giving the same velocity; but multiplying this velocity by their respective sections, it will appear that in order to maintain this velocity the 10-foot sewer must discharge 100 times, the 5-foot sewer 25 times, and the 2-foot sewer 4 times the volume of sewage that is required in the 1-foot sewer.

Hence, in giving an inclination to sewers with a view to rendering them self-cleansing by an increase of velocity, regard must be had to the volume of sewage which may be calculated upon. In general, the smaller the sewer the higher the velocity should be. A house-drain should have not less than 5 feet per second; pipes from 12 to 24 inches should have a velocity of at least 3 feet, while no sewers should, if possible, have less than 2 feet per second.

If these velocities cannot be had by reason of inadequate fall or volume of sewage, there will be reason to apprehend that recourse must be had to flushing at times to keep the sewer clear of deposit. If attention be paid to restricting the dimensions of the sewers to the minimum which the locality calls for, and with falls to give that volume the requisite velocity, the deposit, under an ordinary water-

supply such as most of cities furnish, will not, in general, accumulate beyond what the current rainfalls will suffice to sweep off before the capacity of the sewer becomes materially diminished; and in large sewers it should be borne in mind that it is the slope of the water-surface or the hydraulic slope, and not the slope of the bottom of the sewer, which is efficacious in producing a velocity of discharge.

In reference to the velocity of the current in sewers, the dimensions of which have been determined by Equation (4), we have seen why it cannot be deduced from an estimate of the total discharge in the unit of time, divided by the sectional area of the sewer; but it is desirable that there should be some expression for the velocity with a view to the determination of the resistance to be encountered in the passage of curves, and to make provision for this additional resistance to motion.

The reduced size of the main sewers as proposed, when discharging their maximum (and when, as we have shown, it will be difficult to determine the velocity of their currents *a priori*) have a velocity so much in excess of their needs in respect to preventing the formation of deposits, that the diminution of velocity through the intervention of curves on the line of main need not be regarded, but our attention is called to the circumstances attending the dry summer flow, when the volume of water being discharged has become so reduced as to lessen the current materially, and thus render the formation of deposits on the invert of the sewer possible. To show how far the reduction of the velocity of the current in the sewer may favor the promotion of deposits, we append the oft-published statement from Du Buat, which we apprehend should be taken with some allowance—that is to say, in the lower velocities.

VELOCITY NECESSARY TO REMOVE CERTAIN SUBSTANCES, IN FEET PER SECOND.

River mud, semi-fluid	0.4
Clay	0.5
River sand	1.0
Fine gravel	1.0
Shingle, water-worn pebbles	3.0
Angular shingle	3.4
Broken stone	4.0

And from Robinson on Rivers:

Fine sand	0.5
Coarse sand	0.66
Fine gravel	1.00
Gravel an inch in diameter	2.00
Angular stones of egg size	3.00

Later experiments have demonstrated that when the velocity is as high as $2\frac{1}{2}$ to 3 feet per second, no danger need be apprehended of the retention in the sewers of any material likely to reach them. The reduction of velocity in the passage of the current around curves in the line of sewers, should be met by giving an increase in the fall of the invert at such places; and this, in view of the possibility of a low summer flow at a reduced current, should be introduced into the grade of all sewers, whatever may be their dimensions and presumed maximum velocities.

In our own practice we have made the falls at the curves as great as the circumstances of the locality would allow, to the extent of from 3 to 8 inches on a 90 degree curve with a radius of 20 feet, and with good results, and propose a formula which represents this practice as follows:

It has been shown that the sewage or water-supply does not occupy more than $\frac{1}{2\frac{1}{3}}$d of the bulk of the storm-waters provided for in the capacity of the sewers. If, then, $\frac{1}{10}$th of the sectional area of a sewer be estimated as occupied by the dry summer flow or sewage discharge, the velocity

deduced from this flow on a given inclination, although not strictly accurate, may be safely assumed for all practical purposes as the minimum discharge of the sewers.

In Equation 1 (p. 55), $100\sqrt{\frac{HS}{LP}}$,

H being the fall on a given line of sewer,

L the length, and

S = the area of the pipe occupied by the flow,

P = the length of the wetted perimeter—all dimensions in feet.

If we substitute the values in this formula, and for S assume $\frac{1}{10}$th the sectional area of the sewer, and for P the wet perimeter for this section, we will have the velocity in feet per second of the low summer flow or that of the sewage. To obtain the additional head requisite for the length of *a given curve*, substitute this value just found for v, in the formula

$$h = \frac{vl}{2rD} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

wherein h = additional head for the curve,

l = length of the curve,

r = radius of the axis of the curve,

D = diameter of the circular sewer—all in feet.

Applying this to the example given on page 60 of a case in practice where the sewer is a circle of 6′ diameter with a fall of $\frac{1}{1135}$, and which drains 869 acres; here

$$\frac{H}{L} = \frac{1}{1135}, \quad \frac{S}{P} = \frac{2.82}{4.8}, \text{ and } v = 2.26 \text{ ft. per second.}$$

Substituting this value of v in the equation, $h = \frac{vl}{2rD}$,

wherein h = additional fall to be given the sewer in the length of the curve.

l = length of the curve = 31, 4.

r = radius of the axis of the curve = 20,

D = 6, diameter of the sewer—all in feet.

h will equal .3 = 3.3 inches.

This must not be confounded with the head necessary to overcome the resistance to friction in the curves of circular conduits running with a full bore, as shown by the various writers on hydraulics—Du Buat, Weisbach, Neville, Beardmore, Rankin, Navier—all give varying expressions for the loss of head on curves in water-pipes; and Latham, referring to Weisbach's formula from Du Buat, recommends it for application to sewers; but none of these formula would give for the above example an additional head of more than some fraction of an inch—a quantity totally without value for the purpose of sewer discharge.

The formula (6) which we submit, is entirely empirical, and represents simply our own practice for many years for circular sewers of any diameter, and where the radius of the curve is 20 feet and upwards, and where the dry summer flow can be estimated as less than $2\frac{1}{2}$ feet per second. When the current of the sewer has *at all times* a higher velocity than this, no special provision is needed to meet the retardation on the curves if the sewer be properly built and with sufficient radius, which latter should always be as *large as possible*, and never less than 20 feet.

By velocity, mean velocity is to be understood, which, according to the writers, is about $\frac{4}{5}$ of the surface velocity, and the bottom velocity is about $\frac{9}{10}$ of the mean. But these figures have but little value when dealing with discharges through pipes.

As easily carried in the memory, the following will

represent about the falls which will preserve circular sewers free from deposit, providing they run half full:

For 6″	diameter	a grade of	1	in	60
9″	"	"	1	in	90
12″	"	"	1	in	200
15″	"	"	1	in	250
18″	"	"	1	in	300
24″	"	"	1	in	400
36″	"	"	1	in	600
42″	"	"	1	in	700
48″	"	"	1	in	800

In the junction of branch pipe-sewers a less length of radius is attainable, but the junction of *all* branches should make as small an angle with the main line as the nature of the construction will permit. This latter circumstance will at times forbid the junction being made actually at a tangent, but in such cases great care should be exercised in the construction. This is illustrated in Figs. 40, 42. In the junctions of brick sewers, the axes may always be tangential, but pipe sewer-branches, unless to a short radius, cannot be constructed with a less deflection angle at the junction with brick sewers than about 30°. See Fig. 37.

Thus far we have regarded the sewers as circular in section, and no practical objection exists to so regarding them for the purposes of computation, and, accordingly, whatever their shapes or dimensions may be, it is usual to classify them by their equivalent areas as circles; and for sewers carrying at all times a large volume of sewage, as in the case of mains for a large drainage district requiring say fifteen or twenty square feet of area and upwards, it is not necessary ordinarily to adopt the shape of their inverts to their small volumes of sewage, although circumstances may at times call for it. The advantage of what is called

the "egg-shaped" sewer in concentrating the smaller volumes of sewage is shown in Fig. 6, wherein the greater depth of channel with the same amount of water is shown in the two sections.

For all sizes less than sixty inches in diameter, the egg-shaped section with the small end down should be used.

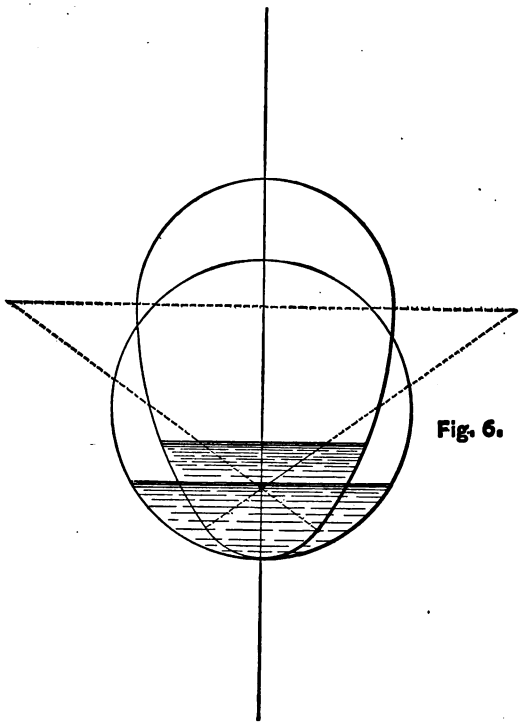
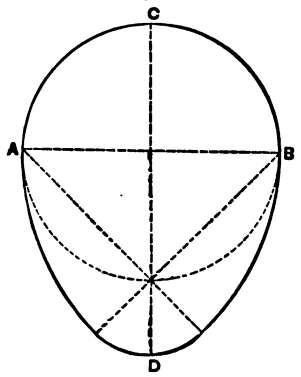


Fig. 6.

For the larger sizes the section Fig. 7 may be used. In the smaller sizes, including pipe-sewers, the section Fig. 8 is to be preferred, and for the reason stated—that the dry weather flow may be so concentrated as to have the greatest possible depth, as shown in Fig. 6. In Fig. 7 the area of this section is to a circular sewer of the same diameter as

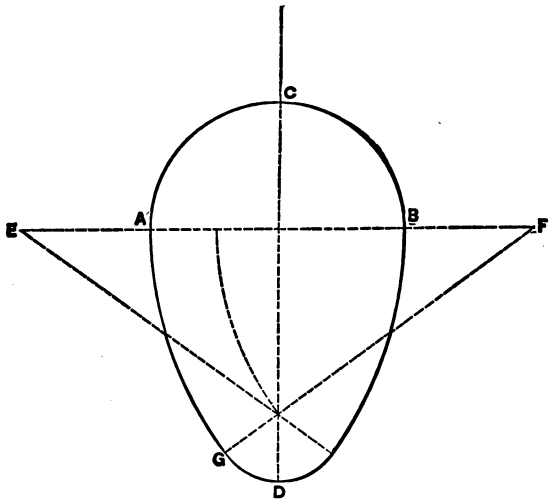
Fig. 7.



996 : 785 or 1.27 to 1; therefore, when the areas are equal, the diameters will be nearly as 8 to 9; and to apply it, find the diameter of the circular sewer capable of draining the district proposed, and deduct its ninth part, the remainder is the horizontal diameter of the equivalent egg-shaped sewer of this section; and add one-eighth to the diameter of this section, and it will give the diameter of the circular sewer having the same capacity of discharge.*

Fig. 8 is the section adapted for pipe-sewers as well as for the smaller class of brick sewers, having in view the

Fig. 8.



principles already stated, which should control this matter. In this section, if the diameter of the upper arch be taken as unity, then

* Mr. Thos. Hawksley.

The diameter of the lower arch will equal .5
The height of the section = 1.5
The radius of the side arches = 1.5
If the height of the section be 1,
The top arch diameter = .66
The invert arch diameter = .33
The side arches radius = 1.

The following table exhibits the proportions of this section for various sizes of sewers, and also their several capacities in square feet sufficiently accurate for general use as sewers:

INTERNAL DIMENSIONS.

HEIGHT IN FEET.	DIAMETER OF TOP ARCH IN FEET.	DIAMETER OF INVERT IN FEET.	APPROXIMATE AREA IN SQUARE FEET.
1·5	1.	·5	1.125
2.25	1.5	·75	2.531
3.	2.	1.	4.5
3·75	2.5	1.25	7.031
4·5	3.	1.5	10.125
5·25	3·5	1.75	13.781
6.	4.	2.	18.0
6.75	4.5	2.25	22.781
7·5	5.	2.5	28.125
8.25	5·5	2.75	34.031

Area = product of the mean of the diameters multiplied by the height.—*Dempsey.*

It will be perceived that this section is not as applicable as is the section Fig. 7 to sewers equivalent to a circle of five feet diameter or over, on account of its greater height, but is to be recommended for the smaller dimensions and for pipes.

In some localities, the depth of filling over the crown of the arch, which in paved streets should not be less than four feet, may not permit even a full circular sewer, in which

case a special section may be called for, such as Fig. 9, or even so undesirable a section as that of Fig. 10, where all consideration of the self-cleansing power of the sewer must be laid aside, in view of circumstances of more paramount importance. The mains which drain large areas of hundreds of acres, carry nearly at all times large bodies of water, and admit of great variations in the dimensions of their section, but preserve a pretty uniform type, such as a full semicircular arch at top, vertical or slightly inclined side walls, and a comparatively flat segmental arched invert. See Fig. 11.

Fig. 9.

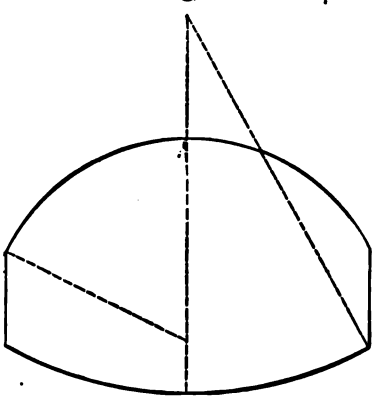
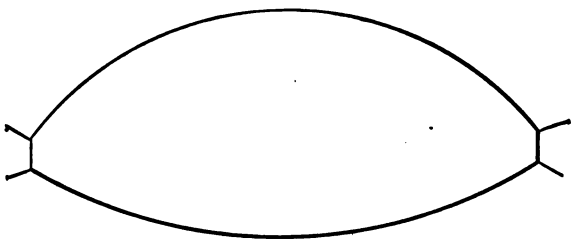


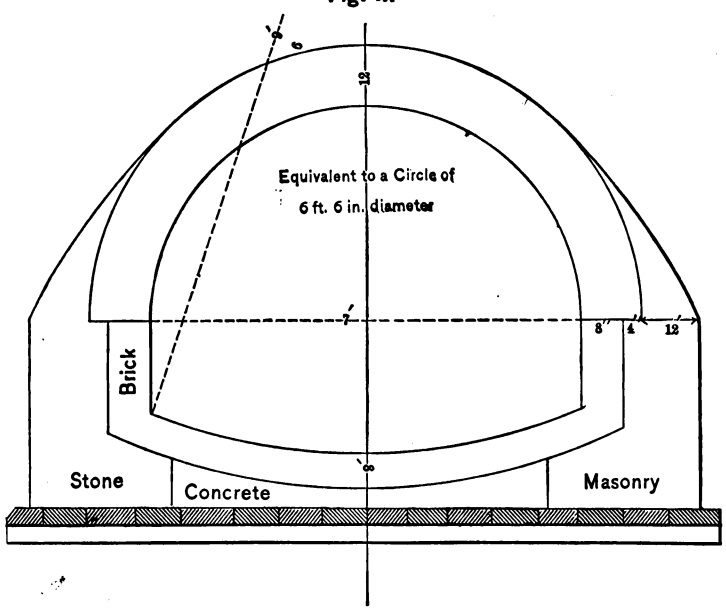
Fig. 10.



The matter of the junction of branch currents is one of great importance in the successful working of a system of sewers. There is no cause so fruitful of disappointment as the neglect of this apparently small matter of rendering the currents of supply to a sewer an aid to the velocity, instead of diminishing the latter by the creation of counter-currents or eddies. In the complaints of householders of

the flooding of their premises, it is found that the introduction of easy bends in lieu of right-angled junctions, and the substitution of correct curves for the irregular polygons which are too often introduced through ignorance or imperfect supervision, removes the difficulty in a majority of cases, and nothing further is heard of the inadequate dimensions of the sewers.

Fig. II.



We have supposed that the surface to be drained is of a generally uniform character and devoid of any exaggerated features, such as would render a special estimate of the volume or times of discharge of the storm-waters necessary. But, should such occur, there will be no difficulty in the application of this formula (4); for instance, in the case of a long main with a very slight fall or inclination, receiving branches from steeply-inclined hillsides on both sides, or

steep slopes on one side and a comparative flat on the other. In such case, each branch near its junction with the main should be proportioned by the formula to the dimensions due the area drained and the slope; and the main below the junction of the respective branches should be computed as discharging from the entire area above it at the determined rate per hour, and with its own special inclination. The difficulty ordinarily in apportioning the amount of rain reaching the main from its various branches, is met by this general assumption of the rainfall on a given area being carried off in double the time of its fall, which is usually so much within the time actually consumed by the discharge as to afford an ample margin for the discrepancies inseparable from calculations made with such insufficient data. But should this not be considered as meeting the case, we would proceed as follows:

RECAPITULATION.—This equation (4) expressed logarithmically in (5) same page, is the formula to be used for the diameter in feet of circular sewers for carrying off the rainfall from 1 inch of rain in the hour, *upon the supposition that it will require two hours for its discharge at the outlet.* Of course, this time will vary sensibly under the varying conditions already enumerated as likely to obtain in different localities; but the formula may be taken, *in general*, as erring on the safe side, and therefore sufficiently accurate for *populous districts built upon in the modern method now prevailing in this country, with wide streets, open court-yards, gardens, parks, etc., and wherever the buildings do not in general exceed the rate of 8 or 10 to the acre.* Wherever more crowded areas prevail, some modification will be called for, *not on account of the increased amount of human sewage*, as previously explained, but from the fact that crowding the area with more buildings and nar-

rower streets and less unpaved surfaces in consequence, a larger proportion of the water from the outlying districts will enter the sewers in a *given time*, than would otherwise be the case. For instance, there are wards in the city of New York where, with narrow streets the buildings are so crowded that nearly the entire surface is covered by roof or pavement, and there are such probably in other large cities; and these districts, instead of being long and narrow, with the sewer taking the longest direction of the district for its length, may be nearly square in outline, and with a correspondingly quick discharge into the outlet. On such districts, of course, the proportion of rain which reaches the sewer in the same time as its fall is proportionally increased, but *it can never reach the outlet in the time of its fall;* gathering the rain on the roofs, yards, gardens and streets by narrow conduits into the sewers must occupy some time, so that it is manifestly inaccurate to estimate the rain as reaching the outlet of the sewers as *rapidly* as it falls from the clouds; and under no circumstances, in our judgment, can over *two-thirds* of an inch of rain falling in an hour be delivered at the outlet of the sewers in the same time.

If it be considered expedient in the above-mentioned or other analogous cases, to estimate this latter amount as reaching the sewer, the formula (4) should be modified by substituting for Q, $\frac{2A}{3}$, and equation (5) becomes

$$log.\ D = \frac{2\ log.\ A + log.\ N - 3.54}{6}.$$

The method to be pursued if it be considered proper to estimate a greater rainfall than that of an inch in the hour, is shown on p. 65.

It will be noted that we do not aim to treat of the motion of clean water in pipes or channels in general, such as

obtains in works of water-supply, nor call in question the accuracy of the received hydraulic formula for such; but what precedes has special relation to sewage discharge in populous districts alone, and aims to indicate practical methods for the computation of the dimensions of sewers carrying off storm-waters in accordance with the results of extended experience, and where the constant accession to the main sewers during and throughout their course bring additional volumes of storm-water with varying velocities and corresponding difficulty of calculation to feed the main current. If occasion arises for conducting storm, or subsoil waters, or sewage in conduits under pressure, or with a known head, *and not receiving contributions from other sources in its route*, as in water-works, the rules for hydraulic engineering which may be found in any standard work on that subject, may be consulted, if greater refinement of accuracy is required than that furnished by the fundamental equation (2) or Beardmore's Tables.

We have now all the data attainable for the determination of the dimensions of sewers in view of their grades, curves, junctions and volumes of sewage; there remains but to apply it with intelligence. No instruction from books or tables alone will enable the engineer to direct this delicate operation. The rules to be followed under certain circumstances may be had, but the ability to judge of these circumstances and how far they should modify general rules, can only result from observation of existing works and a comparison of results attained.

CHAPTER III.

MATERIALS USED IN THE CONSTRUCTION OF SEWERS, AND THEIR APPLICATION.

IT is to be supposed that the engineer has a practical acquaintance of such of the materials applicable to the construction of sewers, as are of general use in other branches of construction, and therefore little need be said of the preparation of these materials, as they would differ in no essential from what would be required in all good building operations.

Brick.—The brick selected for building sewers should in all cases be hard, and well burned; no pale brick from the outside of the kiln should be admitted even for backing, and if the well burned portions of the kiln admit of selection, the best and hardest should be selected for the inverts. The brick should be regular in form, without warp, and with square edges, should give a clear ringing sound when struck, and when broken should exhibit a uniform grain, free from air bubbles, cracks, or coarse pebbles, and present a somewhat glassy fracture, rather than an earthy one, and should be capable of bearing a compressive strain when set on end and subjected to pressure, of at least 1000 pounds to the square inch before crushing, and should not absorb more than $\frac{1}{15}$ of its weight of water. No dependence can be placed upon the recorded experiments of resistance to tensile strain on brick. They all give very variable results, and a comparatively high factor of strength, under special conditions of experiment, which practice disproves

in most cases. The reputation of the maker, and the inspection and selection of the brick by experienced men, are the only guides we can rely upon in this matter.

Cement.—In selecting this material, while the reputation of the manufacturer is not to be disregarded, the behavior of the cement under conditions not very dissimilar from those attending its actual use, can be observed and recorded, and, as a general rule, such a system of tests should always be adopted, where any considerable quantity is to be used, as will tend to insure the best results when placed in the work. Of course no one will undertake the direction of important hydraulic works, without making himself familiar with the literature of the subject of cements, which is too important to be properly treated here, and is ably discussed by General Gillmore in his work on Limes and Cements, to which we would refer the reader.

For our present purpose it will suffice to call attention to a few practical suggestions. The use of quicklime mortar, or the dilution of cement mortar by the introduction of quicklime, cannot be recommended for sewer construction, however admissible it may appear to be on the score of economy for masonry in general. Hydraulic cement is now manufactured in such large quantities, both from the argilo-magnesian limestone (which we shall characterize as Rosendale cement) and by the process of burning lime and clay together at a high heat, forming what is called Portland cement, that the economy resulting from the use of quicklime is very questionable in *works of sewerage.*

If the work is necessarily exposed to wet immediately after laying, as is very usual in the construction of sewer-inverts, a quick setting cement is desirable, even though it be had by some sacrifice in the strength of the cement. The mixture of any material, whether lime or sand, dimin-

ishes very sensibly the strength of all cements. But it is claimed that the same amount of dilution induced by the use of quicklime, if had by the use of sand, renders the resulting cement-mortar more porous; but this need not be apprehended if the constituent materials be properly mixed, nor need this extreme dilution be aimed at. The proportion of sand in hydraulic mortar formed of Rosendale cement should not exceed two volumes of the dry cement, so that each particle of the sand may be enveloped by cement. Theoretically this may be had by three volumes of sand; but owing to unavoidable imperfections in the process of mixing, two volumes of sand is as much as should be used for works under water. With reference to the quality of the cement, and to show what may be accomplished by a rigid system of inspection in improving the strength of

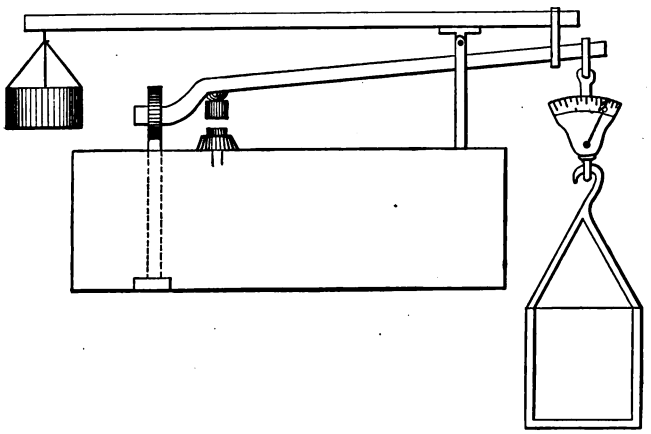


Fig. 12.

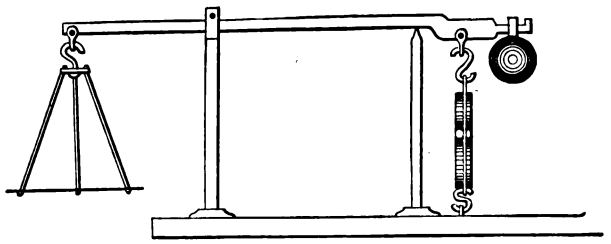
cement, we would refer to the results of Mr. Shedd's efforts in this direction when constructing the system of sewers of Providence, R. I.* The method pursued there was for the city to purchase the materials required for the construc-

* From proceedings of the Am. Soc. C. Engineers, at seventh annual convention, paper by J. Herbert Shedd, vol. 4, 1875.

tion of the sewers and not trust them to the contractor, by which means a more thorough inspection could be had than other and more usual arrangements would have offered.

Inexpensive testing machines both for tensile and crushing strains were provided (see Figures 12 and 13), and a

Fig. 13.



Tensile

sample being taken from each barrel, and numbered to correspond, was mixed with as little water as practicable, and pressed into a circular mould (on left of Fig. 14), giving the specimen one square inch of section at the shoulder or breaking-point. After an exposure of half an hour in the air, the specimens were immersed in clear water for 24 hours, then broken in the testing machine, and their strength recorded. Some 22,500 specimens of Rosendale cement were thus tested, of which about one-tenth were rejected. The result was, that while at the commencement of the work it was difficult to obtain cement which would stand a tensile strain of 30 pounds to the square inch after 24 hours' immersion, the efforts of the makers to reduce the amount of rejected cement so improved the quality that it soon rose to 60 pounds tensile strength.

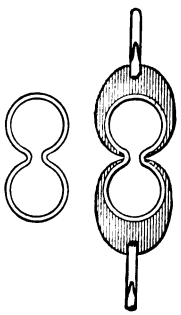


Fig. 14.

The American Portland cement, treated in precisely the

same manner as the above, will show a tensile strength of considerably over 200 pounds to the square inch, or three times the strength of Rosendale cement, and its use is to be recommended when great tensile strength is required; and it will admit of a greater dilution with sand—that is to say, permit of more sand being used in its mixture into mortar —without bringing its strength below Rosendale cement; but for work built in running water, and imperfectly drained, as before hinted at, a quicker setting cement than Portland cement is desirable, and this is furnished by the American natural cement known here as Rosendale cement, which is manufactured by burning the argilo-magnesian limestone, which is found in many parts of this country. After burning in kilns, the stone is ground fine between millstones, precisely as flour is ground. Portland cement is ground in the same manner after burning; indeed, no stone which by burning furnishes cement, slacks after burning as does quicklime, but requires to be ground.

By rigidly pursuing the course adopted by Mr. Shedd, the character of the Rosendale cement would soon become uniformly improved in all the qualities requisite for sewer construction. The cost of testing is stated to vary from 1 to 3 cents per barrel, of course dependent somewhat upon the amounts rejected.

Tests.—Rosendale cement should be ground so fine that at least 90 per cent. of it shall pass through a No. 30 wire sieve of 36 wires to the linear inch, and should weigh not less than 68 pounds to the struck bushel of loose cement, and should contain, when mixed without sand and allowed twenty-four hours to set and afterwards immersed for six days in water, 60 pounds tensional strain per square inch of section.

Portland cement should be ground to the same fineness

as the above, but should weigh not less than 106 pounds to the struck bushel of loose cement, and made into paste without sand, and after twenty-four hours' exposure to air, and six days in water, should stand a tensional strain of 170 pounds to the square inch of section.

It should be observed in comparing the behavior of these two cements under test, that the preparation was the same in each, and resulted in showing the very great superiority in the strength of Portland cement; but in many sewer-constructions it may become desirable or necessary that the cement be subjected to the flow of water within an hour or even less after being used in the work, in which case a Portland cement with the proportion of quicklime (which is sometimes used, we think, improperly) and sand to bring the cost at nearly the same as that of the Rosendale, would not have the requisite "set" or hardness to withstand the effect of running water, whereas the Rosendale cement properly treated could be depended upon in such cases. In testing the fitness of the cement for such latter use, the needle test * will be sufficient.

Sand.—The sand used in cement-mortar should be sharp and clean, rather coarse than fine, and free from clay or loam; and whether pit or sea sand it matters little, providing that the above requirements are fulfilled. If at all dirty, the sand should be washed and dried. If Rosendale cement be used, two volumes of sand to one of cement, both dry, should be first mixed, and then a sufficient

* The needle test consists in working up a paste of the cement under trial with water, so stiff that a wire of $\frac{1}{12}$ inch diameter, loaded with $\frac{1}{4}$ pound, will barely make an impression, placing the specimen in water and judging of the hydraulic properties of the cement by the time it takes to "set." Some specimens will set immediately, others will require days, and even weeks. The setting alluded to consists in the ability to resist a weight of one pound on a wire of $\frac{1}{24}$th inch in diameter.

quantity of water added to bring the mixture to the consistency of a thick paste, and thoroughly turned and mixed with hoes and shovels, on a plank bed; but, if the magnitude of the work justifies it, a mortar-mill may very properly be used.

Concrete. — In preparing concrete, the cement-mortar above described should be spread in a thin layer, and five volumes of broken stone, brick, or shells, after being washed of all clay or dirt, and while wet, should be spread over the cement and turned and mixed thoroughly until each fragment of stone is enveloped in a layer of cement. The concrete should then be deposited immediately in place in the work. No particular importance need be attached to ramming the concrete, further than insuring that no vacuities are left in it, but that the mass is solid throughout. The broken stone or brick should not be larger than will pass a $2\frac{1}{2}$ inch ring. If the stone were clean before being broken by machine, the finer particles resulting from the crushing in the machine need not be screened out; but if the stone were dirty, the broken stone should, after crushing, be washed or screened.

Timber.—The timber used in sewerage works is mostly for temporary use. If intended to remain in the work, it is either under water, and so not liable to rapid decay, or so placed that its final decay will not be attended with any injury to the permanence of the works. Pine, spruce, hemlock, and the cheaper timbers are suitable for shoring trenches and such purposes, and pine, oak or chestnut, or other hard wood, is suitable for foundation timbers. In either use, sound merchantable material is all that is required, applied in a workmanlike manner by skilled mechanics.

Clay Pipe.—Although the clays suitable for the purpose

of sewer-pipe abound in this country, and of excellent quality, the demand, except for inferior uses, as agricultural drains, has been too limited, until a few years past, to induce the necessary capital for their manufacture; and in consequence, we have been largely indebted to the Scotch wherever better pipe than ordinary were required. Latterly, however, the extension of the pipe-sewer system has been so great that manufactures have sprung up in all parts of the country, and vitrified clay pipe are now made in no way inferior to the best imported pipe, and much cheaper in cost. We may unconsciously be doing injustice to other makers whose productions are equally good, but which have not been brought to our notice; but the sewer-pipe from the Akron Sewer-Pipe Company's works, of Ohio clay, and the pipe of the Jersey clay made by G. W. Rader of New York, are equal in excellence to any imported pipe. Both establishments are of the oldest in the country. The first is a salt-glazed pipe, and the second is a slip-glazed pipe. That the merits of both may be judged of fairly, the clays used and the process of manufacture will be found described more at length in the Appendix.

Natural clays are rarely found of the precise ingredients suitable for manufacturing sewer-pipe. Pure clay is infusible in any heat, as also is pure silica. These are the chief ingredients which are used. The other constituents which enter into the composition of clays are lime, magnesia, oxide of iron, potash, and soda. If a clay is rich in alumina and silica, the former predominating, the alkalies absent or in limited quantities, the clay is what is called refractory, and is suitable for fire-brick, crucibles, and articles intended to be subjected to a high heat, but is porous, and requires the addition of some form of the alkalies, which, acting as a flux, serves to semifuse or vitrify the

silica, giving it the density required for sewer-pipe. The first sewer-pipe made here, and indeed much of the pipe even now made, in the effort to confer this hardness deemed necessary, becomes too brittle, and lacks the toughness which was so apparent in the best Scotch pipe. The body of the latter is not a pure fire-clay, but the term is used to distinguish it from stone-ware pipe, which has a hard vitrified body, suitable for various domestic purposes, but considered less suitable for sewer-pipes. The clay beds from whence the materials for these pipes is taken, differ most essentially in the different localities, and even differ at times in the same locality to such an extent that the manufacturer himself is not unfrequently misled in the character of his pipe until after they are burnt in the kiln, and even then he is unable to form a correct judgment of them by the eye alone.

From the above hints it will be seen that the burnt clay pipe may offer every variety in their quality from a brittle stone-ware pottery to a fire-clay pipe, and their value for sewers is very dependent upon the selection and preparation of the material, and the proportion of foreign ingredients admitted into the manufacture, and much discretion is to be used in their selection; and hence, the reputation of the maker must be the best guide in the selection of such pipe for sewer purposes until trial in actual works shall have indicated the character of the pipe.

The thickness of the pipe is made to vary somewhat with the material of which it is composed, the stone-ware being slightly thinner than the fire-clay. The best pipe are not only hard but tough, and should be perfectly homogeneous in texture, and uniform in thickness, and true in section, perfectly straight, without warp, and free from fire-cracks, and should be glazed uniformly inside and out, and the

preference appears to be for a salt glaze, and when struck should give a clear metallic sound.

Our preference when using burned clay pipe is for the cylindrical pipe without sockets, and laid with a sleeve of the same material as the pipe. This use of a sleeve admits of more certainty in the character of the joint, and also permits of a defective pipe being removed from the line after it is laid without disturbing any of the neighboring joints. The strength of the pipe to resist a cross-strain or pressure such as it may be subjected to in the trench, may be ascertained to a certain extent by trial under a lever-press as shown in Fig. 15, and the crushing strain of the

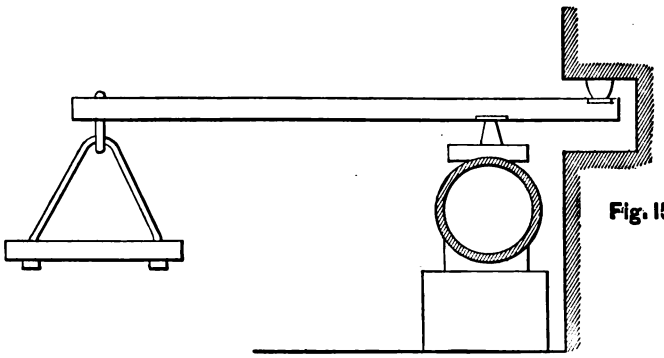


Fig. 15.

materials composing the pipe may be ascertained by subjecting pieces of the pipe ground to uniform section, to a crushing strain in a hydraulic press.

From a report made to the Commissioners of Drainage of the City of Brooklyn by the author in 1859, we quote as follows:

The strength and durability of these pipe have been questioned. Those at first used for drainage were quite thin, frequently but one-half inch thick for pipes 12 inches in diameter and over, and of a light porous body, similar to drain-tiles, and without glaze, called "red earthenware

pipes." The thickness alone is not a criterion of the strength of the pipe. The London made stone-ware pipe, for instance, are yet made comparatively thin, the quality of clay used seeming to involve the necessity for so proportioning them. They are about 25 per cent. more expensive than the earthenware, but when properly burned, form a true pottery, or "stone-ware," very hard, vitreous, not yielding to the knife, taking a good glaze, resisting a uniform pressure well, perfectly impermeable and imperishable, but liable to fracture by a sudden concussion or cross-strain. The Greenwich pottery-ware pipe, manufactured in New York, is of this description. The pipe imported for use in this city, from Glasgow, Scotland, and the north of England, are entirely different from the above, being manufactured, to appearance, of a strong fire-clay, resisting a high heat, and admitting of any required thickness and consequent strength. This description of pipe is believed to be less brittle and less liable to fracture in the handling, and better suited to the purpose of a sewer than pottery-ware. It is required to be of greater thickness and to be well burnt throughout, and rendered impermeable by the glaze which should have become incorporated with the material of the pipe, and not liable to separation from it. The clay for this description of pipe is found in this country, but there has been too little demand for it hitherto to encourage its manufacture.

The following are selected from a number of experiments made for testing the strength of materials:

A piece of American white marble (Stockbridge), 2 inches square and $\frac{7}{8}$ inch thick, crushed to powder by a pressure of 45,000 lbs., or a little over 12,000 lbs. to the square inch.

A piece of Chelsea pottery pipe, hard-burned, 2 inches

square and $1\frac{1}{8}$ thick, bore the whole power of the press, viz.: 54,200 lbs., or over 12,000 lbs. to the square inch, without sensible injury.

A piece from a pipe of Quinn's manufacture (Williamsburgh), $2\frac{1}{4}$ inches square and $\frac{7}{8}$ inch thick, also bore the whole power of the press, 54,200, without yielding.

A piece from a pipe manufactured by W. Smith (Greenwich Pottery), $1\frac{3}{4}$ inch square and $\frac{1}{2}$ inch thick, bore the whole pressure of the press without injury.

A piece of Rosendale cement, two years old, a very fine specimen, 2 inches in diameter and $\frac{5}{8}$ inch thick, was broken by a pressure of 10,200 lbs., or 3,270 lbs. to the square inch.

A piece of hard-burned brick, such as is used in the construction of sewers, $3\frac{3}{8}$ by $1\frac{7}{8}$ and $1\frac{7}{8}$ thick, was crushed by a pressure of 13,800 lbs., or 3,630 lbs. to the square inch.

A piece of Garnkirk (Scotch) pipe, $2\frac{3}{4}$ by $2\frac{1}{4}$ and 1 inch thick, also bore the whole power of the press without injury, as did a piece of imported pipe from Hammel's, 110 Pearl Street, $2\frac{1}{4}$ inch square and $\frac{5}{8}$ inch thick.

Some of the specimens, softer burned, were crushed by less weights, but all experimented on proved stronger than the ordinary brown stone which Mr. Hatfield had previously experimented on with the same press, and although these experiments are not absolutely conclusive as to the relative strength of the specimens to resist crushing, are yet sufficiently so as to the strength of the material in general of which these pipes are composed.

To test the pipe still further. If the pipe in the trench were equally compressed on all sides, the great strength of the material to resist crushing would prevent any fears of their ever giving way; but this is not the case. From the slipping of the earth in the trench, inequality in bearing, and concussion from heavy traffic, the pipe is exposed to

unequal pressure, the nature and extent of which it is impossible to estimate. To put the pipe to a proof, severer beyond question than any trial to which it is likely to be exposed, was the only method in our power for testing its strength under the ordinary accidents of its service as a sewer. Accordingly we have tested the pipe in the following manner: Fig. 15.

A pipe three feet long is made to rest upon two bearings at the bottom of 8 inches in width each, and receives pressure on top, at the centre, on a line as it were, 12 inches in length.

A Garnkirk (Scotch) pipe, $17\frac{3}{16}$ inches in diameter, $1\frac{1}{16}$ inch thick, bore 5,542 lbs. The Ferguslie and Pierson pipe (Scotch), 12 inches and 15 inches in diameter, and $1\frac{1}{8}$ and 1 inch thick, bore respectively 4,000 and 3,800 lbs. The Chelsea Pottery pipe, 12 inches in diameter and $1\frac{3}{8}$ inch thick, bore 4,600 lbs., and the Greenwich Pottery pipe, of 12 inches in diameter and $\frac{7}{8}$ inch thick and but 2 feet in length, bore but 1,672 lbs.

All the pipes were split by these trials into four pieces, lengthwise of the pipe. These experiments also illustrate a previous remark, that the stone pottery-ware, although extremely hard, is lacking in the element of toughness, and hence is inferior for our purpose to the imported pipe, or to pipe made after the same method. Still another test was needed of the strength of pipe, viz.: to resist the internal pressure of water flowing through it. The sewers are not designed, as are the pipes of water distribution, to carry off the water under pressure, but in the event of a complete stoppage, they would, it is true, be subjected to internal pressure. Our experiments to test their strength to bear this pressure are not as satisfactory as could be wished. In packing the pipe in the press for

the purpose of experimenting, many pipes were broken by the unequal bearing and cross-strain induced by the effort to effect a tight joint at the ends, which in burning necessarily had become more or less warped—hence the pipe was badly strained before applying the hydraulic pressure. We have proved them with a head of 150 feet, and are satisfied that ample strength is afforded by these pipes for a far greater head than they can by any possibility be subjected to in a sewer.

In order to test the durability of stone in resisting the action of frost, it has been the practice to boil the specimen in a strong solution of sulphate of soda and then exposing it to the action of the air; repeating this process for several days, the crystallization of the salt disintegrates the particles of the stone, and produces an appearance on the surface and the edges precisely similar to the action of the frost after an interval of several years. Good brick, some marbles, Connecticut river sandstone, granite, and the stone-ware pipe experimented on, stood this test perfectly. Whilst the Jersey sandstone, the Nova Scotia stone, the Caen stone, and others, were seriously affected by it—the edges and surface destroyed as if from long exposure to the weather—and though the pipe will not be exposed to frost or the weather, the experiment furnishes a fair test of the comparative durability of the materials experimented on.

Cement Pipe.—All clays shrink more or less in the burning, and sometimes, from the varying character of the ingredients, very irregularly; and in the use of a flat bottom, which is found very desirable in pipe sewers, it is found impossible to so mould them that the shrinkage shall be uniform; and as uniformity in the bore is of prime importance in order to a perfect line of pipe, which shall not

present obstacles at the joints against which filaments in the sewage may collect, and form nuclei for the deposition of heavier parts of the sewage, it was desirable that some material should, if possible, be introduced for pipe sewers which, while affording all the requisite strength and durability, should retain the shape which it had received in the mould. Hydraulic cement, from its well-known property of increasing in hardness from year to year, in situations where all other materials without exception, save the precious metals, disintegrated and wasted away, offered itself as suitable to the required use, and the difficulty of moulding a pipe of varying thickness, with a flat bottom, and which would preserve a true bore after burning, was by its use done away with, and such pipe, when properly made, of good materials, and seasoned before use, have given entire satisfaction.

It has been argued against their use, that one could not arrive at a correct opinion as to the quality of the cement used in their manufacture, until after the failure or success of the pipe itself—when too late, possibly. This is true, but it is equally true that with the stone-ware pipe, reliance must be had upon the judgment and integrity of its makers; for a communication now before us from one of the first makers of stone-ware pipe in this country states it as in his experience, that when he strikes a new stratum of clay in his bank he invariably tests it by fire, as previous to this practice (some ten years since) he had found that clays which, when worked into pipe, and which to the eye had every appearance to recommend them, might yet prove after burning to be entirely unsuited to their purpose.

Burnt clay itself is presumed to be almost indestructible by the agencies to which it may be exposed under ground, and so is an ordinary quality of cement; but the latter is

believed to improve indefinitely from year to year, while we have most unmistakable evidence that the former is at its best when first made. Some burnt clay pipes undergo a decided change owing to lack of homogeneity, occasioned possibly by imperfect manipulation or injudicious mixture of materials, and give way under long-continued pressure.

What would become of our stupendous works of internal improvement, if the concrete upon which they depend entirely for the stability of their foundations was liable, either from age, dampness, or any of the agencies to which it may be exposed under ground, to crumble and decay? And yet published statements abound from city officials in this county, who have used cement sewer-pipe, and who have found them after a short time (within a year in one instance) crumbling and worthless.

That this is not what might be expected of the material itself is too well known to admit of question, and therefore the defect of the pipe consisted, not in the fact of having been made of cement, but in the quality of the cement used and the mode of its manufacture.

It is urged that the acids generated in the sewers have a corroding effect on the cement, while no such effect is apparent on burnt clay. The rapid current of sewage, mixed with the silicious detritus of the streets, has undoubtedly a grinding action on the surface exposed to the wear, against which no material is proof, let its composition be what it may; but we have seen nothing in practice to cause any apprehension as to corroding action of acids in the public sewers. No acid is generated by the decomposition of sewage of sufficient strength to act injuriously on the cement. The spent products from some manufactories might do so to some extent, and we have witnessed its effects in the drains from such, but without attention being called espe-

cially to the action on cement. This is a private matter, however, which those interested should be compelled to provide for, and not be permitted to waste into the public sewers. The dilution which such discharges will encounter upon entering the street sewers may be expected (save in extreme cases) to prevent any undue action upon the cement of sewers, as also upon that in the joints of the brick-work.

In testing the action of nitric acid on lime and cements, it appears that with a solution of water and $\frac{1}{10}$ of a volume of pure nitric acid, in which the limes and cements were immersed for ten days, common quicklime lost from 33 to 95 per cent. of its weight, while Portland cement lost less than 5 per cent., and Roman cement still less, only $3\frac{1}{2}$ per cent.; but nothing like the strength of the above solution, ten times further diluted, can be anticipated as wasted into the sewers. The formation of such acid, however, in a highly diluted form, may be had by the known action of ammonia on lime; thus,

Experiments* on the composition of London sewage show its constituents to average as follows: Of 100,000 pounds by weight of London sewage there were of

Total Solids in Solution.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Total Combined Nitrogen.	Chlorine.
$64\frac{1}{2}$	$4\frac{1}{3}$	$2\frac{1}{2}$	$5\frac{1}{2}$	7	10

This analysis was made under the intermittent system of water supply, of not to exceed 25 gallons of water per inhabitant daily. Our own more generous supply, extending from 50 to 100 gallons daily, would reduce the respective ingredients above shown in the same proportion, being

* From First Report of Rivers Pollution Commission, London.

gathered, as in the London analysis, at the sewer's outlet; so that of 100,000 pounds of such sewage, not over 2 pounds of ammonia would be had. The ammonia in contact with common lime is converted by oxidation into nitric or nitrous acid, which combines with the lime to form nitrites or nitrates of lime, and this being extremely soluble in water, is readily washed out of the joints of brick-work, leaving nothing but the sand, which in its turn also soon disappears. One remedy for this would be to use cement of a quality to resist this action, and without any admixture of quicklime, which is open to its attacks.

It is not uncommon to find in brick sewers which have been built for some time—and indeed the same may be said of almost any brick-work removed from sight—that the mortar is partially or wholly gone in the joints; and this, in the case of sewers, is frequently attributed to the action of the acids from the sewage, but we are satisfied that such failure in the majority of cases has arisen from poor materials or imperfectly supervised workmanship, for we have found that after repointing these joints in a proper manner no such decay has shown itself; and, in truth, no one who has witnessed the ordinary operation of building where hydraulic cement is used need go to the realms of chemistry to account for failure of the joints of brick-work. The cement-mortar, if properly mixed in the first instance, is too often, after partial setting, worked over with water, and in various ways the original intent and meaning of the use of quick-setting cement entirely lost sight of in its application, and the resulting mortar is frequently but little better than so much sand and water.

In contrast with the slovenly workmanship of our brick-work in the preparation of mortars, we see it stated that in some recently cleared-out subterranean water-courses in

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Rome, the brick lining has itself disappeared, leaving a honey-comb of projecting mortar! (Johnson's Encycl.)

In view of the known capabilities of hydraulic cement, when properly applied, we were induced to favor its use in years past as preferable to the burnt clay pipe of American manufacture then in the market, and much cheaper than the imported pipe. The great improvement which a large demand has brought about in our American stone-ware pipe has brought the two descriptions of pipe nearer to an equality, only that the cement-pipe still possesses the advantage of being made with a flat bottom and of precisely uniform bore, which, as we have shown in the first case, cannot be had in the burnt clay pipe, and to obtain the second, requires more care than it often receives; and a certain homogeneousness between the texture of cement-pipe and the cementing material used, favors their water-tight union and the permanency of the joints. This necessity for the early use of cement pipe in competition with inferior stone-ware, has resulted, however, in exhibiting its capabilities; and as a single well-attested fact may very properly balance a volume of hypotheses, the existence to-day of some 168 miles of cement pipe-sewers, some laid nearly twenty years since, and in successful operation in the city of Brooklyn, would forbid its condemnation, whatever might be thought of it as an argument for its extension elsewhere.

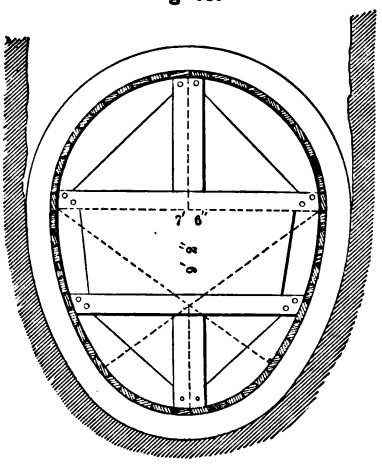
Where any doubt exists as to the quality of the clay, or the pipe made from it, we should recommend the use of cement-pipe of an established manufacture. In Germany its use has been quite extensive, and proved satisfactory both as to strength and durability. But the advantage to be derived from the use of cement or concrete sewers consists in the ability to construct them of this material *in situ*, either wholly of concrete, or with a half-inch ring as a centre

upon which the concrete is formed. This description of sewer, Fig. 33, will be found applicable to many situations, such as rock cutting or in hard excavation. The cost in such situations will be less than that of a brick sewer, and equally efficient.

There are many miles of entire concrete sewers in Paris built in the trench, and we quote from Mr. S. T. Beckwith's Report the following Table of their cost and the method of their construction:

Dimensions of Sewer.			Cubic Feet of Concrete per Linear Foot of Sewer.	Entire Cost per Linear Foot, including Cost of Excavation, Centering and Masonry.
Height, feet.	Width, feet.	Thickness, inches.		
9.2	7.5	10.6	26.15	$5.92
9.	6.5	9.45	22.	5.
7.9	5.6	7.87	15.6	3.53
4.5	2.3	10.25	9.25	2.35
7.	4.25	7.87	14.64	3.31
6.5	3.25	7.87	12.46	3.18
6.25	2.5	7.87	12.	3.04
5.5	2.5	7.87	11.	2.84

Fig. 16.



The trench being excavated, Fig. 16, the concrete is laid to form, and the centering timber put in giving the shape of the sides and arch. The concrete is then tamped by common laborers. After the concrete sets sufficiently to preserve its shape, the centre is struck and advanced for a new section. The thickness of the concrete is about the

same as for a brick sewer. We cannot but think that this method of constructing concrete sewers in the trench (when of large dimensions) offers great advantages when the locality will permit.

In the case of brick sewers, it is well known that great difficulty is found in obtaining a complete water-tight structure, and that with whatever seeming care they are constructed, they are not, in the majority of cases, what the theory of the "water-carriage" system calls for, viz.: impermeable, and when formed of short lengths of pipe, whatever be the material, the multiplicity of joints offers many additional points, wherein leakage may be anticipated; whereas the concrete sewer, or the combined concrete and brick sewer, Fig. 33, is without a *through* joint in its entire length, and when built of good materials, and with ordinary care, may be expected to give the best attainable results.

We would remark here, in concluding what we have to say on the use of cement pipe, as well as that of building entirely of concrete *in situ*, that uniformity in the bore of pipe-sewers at their junctions, as well as the impermeability of the sewers, cannot be too strongly insisted upon. In small sewers, *all* the liquid portions of the sewage is needed to aid the volume of the current in dry weather in its self-cleansing action. In larger sewers, while the loss of liquid by leakage may not be felt to this degree, it is not unusual to find the subsoil drains filled with sewage, and such sewage could only have proceeded from leakage in the joints of the brickwork; and failing such subsoil drains, this sewage would accumulate to poison the subsoil, which, in localities where the filling of earth is shallow, would prove very objectionable.

We append a table of the test of sewer-pipe of various makers, made in 1876; also one made in 1878.

TESTS OF 12-INCH SEWER PIPE MADE IN BOSTON, 1876, BY W. H. BRADLEY, SUPERINTENDENT OF SEWERS.

The pipes were three feet long and without sockets, except as noted.

The crushing test was made by bedding the pipes, horizontally, half their depth in sand and crushing them by a weight applied uniformly along the length, on the top; figures are pounds per foot of length (average of 3 pipes).

The breaking test was made by supporting ends of pipes on two blocks 2 ft. 6 in. apart and applying weight at centre; figures are total weight (one test).

The abrasion test was made by applying a section ½ inch square, loaded with 20 lbs. to a revolving grindstone 3 ft. in diameter, kept wet and clean; figures are revolutions necessary, 1st, to remove glazing; 2d, to grind away $\frac{1}{10}$ of total thickness including glazing (average of two tests).

Tests were also made in bursting, in freezing, and in capacity for absorbing water.

Owners and Kind of Pipe.		Weight, lbs. per ft.	Thickness, inches.	Specific Gravity.	Crushing Weight, lbs. per ft. length.	Breaking Weight, lbs. on 2 ft. 6 span.	Abrasion. Glazing.	Abrasion. $\frac{1}{10}$ thickness.	Color of Fracture and Remarks.
Lewis & Willet, Ag'ts, Tallmadge Co., Ohio	Eastern Vitrified Clays.	41	1.00	2.35	2,265	3,982	42	224	Very Dark Red.
D. L. King, Sec'y, Akron Co., Ohio		40	0.99	2.29	2,236	3,853	37	200	Dark Red.
T. W. Carter & Co., Agents, Hill Co., O.		41	1.04	2.27	2,227	4,350	53	259	Dark Red.
Wyoming Co., Penn. Fire Clay		46	1.13	2.18	1,886	6,132	60	94	Yellow Red. Socket Joints.
Wm. Nelson, Jr., N. Y. Scotch J. B.		43	1.12	2.19	1,875	3,982	9	32	Light Red.
R. G. Walmsley, N. Y. " R. B. S.		44	1.22	2.07	2,458	4,903	22	75	Light Red.
J. Edmond & Co., Boston. "		45	1.19	2.10	2,244	3,368	12	29	Slaty Brown.
Portland Stone Ware Co		37	1.02	2.06	2,140	3,613	10	35	Yellow White.
G. W. Rader, N. Y		41	1.11	2.07	1,510	3,675	7	15	Reddish White.
T. W. Carter & Co., Boston		41	1.10	...	2,144	4,597	8	17	Reddish White.
Salamander Co., Woodbridge, N.J.		43	1.10	2.19	1,606	3,670	8	17	Reddish White.
O.O. Bowman & Co., Trenton, N.J.		42	1.16	2.03	1,438	4,903	10	42	Slate.
R. G. Walmsley, Agent, Jefferson Co., Ohio		41	1.07	2.18	2,070	.....	15	34	Reddish Yellow. 2 ft. Length.
Edmands & Co., Charlestown		36	0.95	2.00	1,905	.....	13	32	Yellow White. 2 ft. Length.
F. B. Day, Boston, Portland Cement (round)		67	1.62	2.19	2,640	5,211			Light Gray. Socket Joint, 6 mos. old.
F. B. Day, Boston, Portland Cement (flat bottom)		76	1.58	2.19	2,919	.....		199	Socket Joint, 6 mos. old.
Lewis & Willet, Boston, Portland Cement (flat bottom)		68	1.50	2.21	2,940	.....	..	154	2 ft. Length. 1 year old.
Lewis & Willet, Boston, American Cement (flat bottom)		64	1.60	....	2,424	.....	..	37	2 ft. Length. 5 mos. old.

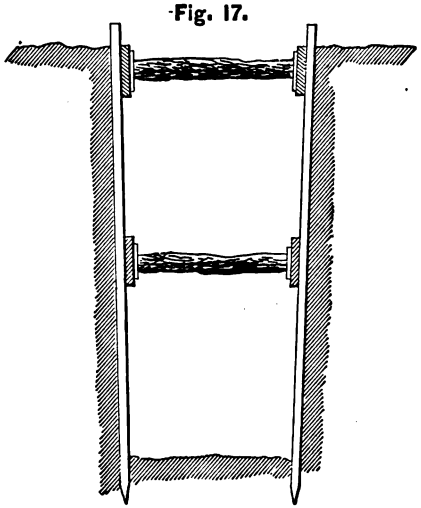
TESTS OF 12-INCH SEWER PIPE MADE IN BOSTON, 1878, BY W. H. BRADLEY, SUPT. OF SEWERS.

OWNERS AND KIND OF PIPE.	Weight in lbs. per foot.	Thickness, inches.	Specific Gravity.	Crushing Weight, lbs. per ft. length.	Breaking Weight, lbs. on 2⅓ ft. span.
D. W. Lewis, Agent, Tallmadge Co., Ohio	42.	1.03	2.48	2107	4606
D. L. King, Secretary, Akron Co., Ohio	40.3	0.99	2.25	1891	3992
Hill Sewer Pipe Co., Ohio	40.5	1.	2.32	2286	4299
T. W. Carter, Agent, Buckeye Co., Ohio	40.5	1.01	2.31	2140	4299
Otis & Gorsline, Rochester, N. Y.	47.7	1.16	2.26	2807	4299
Portland Stone-ware Co., salt glazed	41.1	1.16	....	2495	....
" " " slip "	40.6	1.16	2.11	2652	4913
G. W. Rader, New York, salt "	40.4	1.04	....	1880	....
" " " slip "	40.	1.10	2.17	2052	4299
Marcellus Day, Boston, Portland Cement	63.	....	...	2316	5836
G. Richardson, Philadelphia, Carbonized Stone, 12″ × 18¾″.	81.1	1 to 1.75	2.32	2021	....

CONSTRUCTION OF SEWERS.

The grades and curves being established, showing the depths of the invert of the sewer below the street grades, or below the levels of the curb if the latter be set, and the lines and points of tangency referred to marks on the curb line, or any method of reference which the intelligence of the engineer may point out as best suited to the accuracy of the work, the centre line of the trench is marked out for a width in the clear of two feet greater than the outside of the finished work. If the cut be deep, some additional width should be allowed for the side slopes, but ordinarily the trench may be cut without side slopes, the sides being protected from giv-

Fig. 17.



ing way by heavy plank sheeting, which in their turn are kept in place by stringers and struts, the latter usually of rough whole timbers and wedged firmly to the stringers to prevent any slipping of the earth, and at such intervals as the nature of the material excavated calls for (Fig. 17). If the trench is deep, a second line of sheeting is driven within the first, and secured in the same manner, and so on until the requisite depth is attained (Fig. 18). This sheeting is withdrawn as the back filling of the trench proceeds, after the completion of the sewer; but in treacherous earth or quicksand, and where the street is narrow and built up, and disturbance of the foundations of the buildings on either side is to be apprehended by the movement at the bottom, it is not always safe to remove this sheeting, and it is prudent to leave it, although it will decay; but it may be expected to take place so gradually and irregularly, that the vacuities occasioned thereby become filled by the combined action of the heavy traffic of the street and the percolation of moisture.

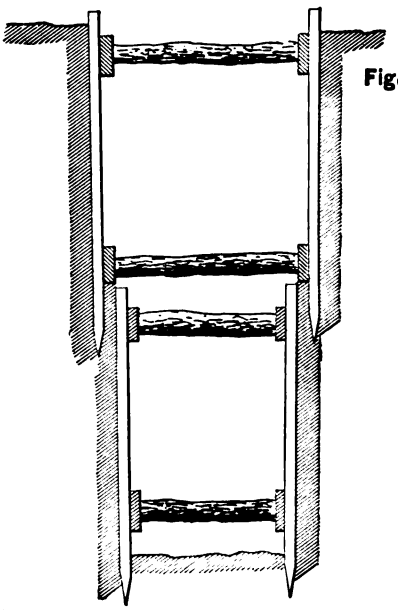


Fig. 18.

Before proceeding to build the sewer, if of brick, or to lay the pipe, if the latter material be used, the grades and centres of alignment are transferred to a joist or heavy plank which spans the top of the excavation and is securely

fastened, at say every 50 feet on straight lines, and at shorter distances on curves, and from the marks made on these joists the foreman plumbs the alignment to the invert, and transfers the levels by a graduated rod. It is of the first consequence that both the alignment and levels should be truly laid out—much more so than in ordinary hydraulic work—and the work constructed in accordance with these accurate measures; neglect in attending to these essentials is a frequent source of trouble, in facilitating the formation of deposits in the sewer.

FOUNDATIONS.

Irregularity in the settlement of sewer-foundations is a great source of mischief in their subsequent working, and no works require greater care in the preparation of the foundations, and it is a miserable economy which admits, in this branch of the work, anything inferior in the way either of materials or workmanship.

Where the bottom is firm and dry, or sufficiently so to preserve its shape, nothing further is needed than to exca-

Fig. 19.

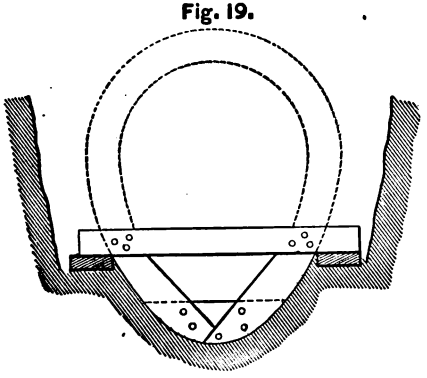
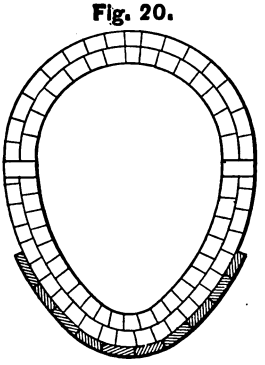


Fig. 20.



Cradle of plank

vate it to a templet for the exterior curve of the invert, as in Fig. 19. Where less firm and coherent, a cradle of

plank laid lengthwise of the trench will facilitate the correct formation of the invert, as in Fig. 20. In wet bottom

Fig. 21.

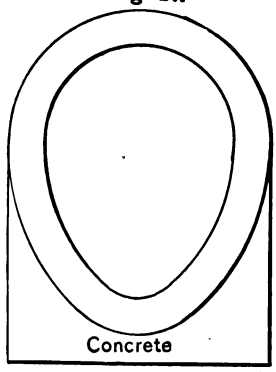
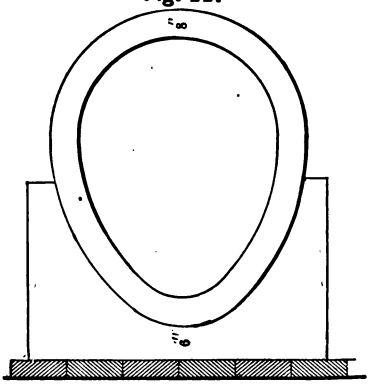


Fig. 22.



of varying character, a bed of concrete as in Fig. 21 will suffice. If the bottom is not firm, a grillage of heavy plank something wider than the sewer, as in Fig. 22, will be required; these latter to be crossed by another layer at right

Fig. 23.

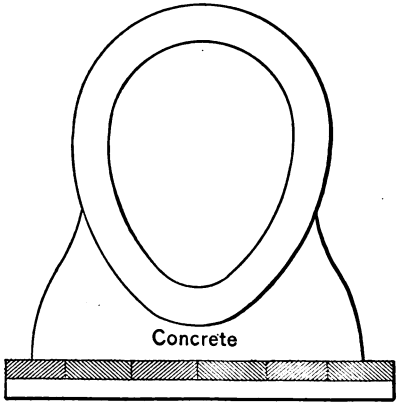
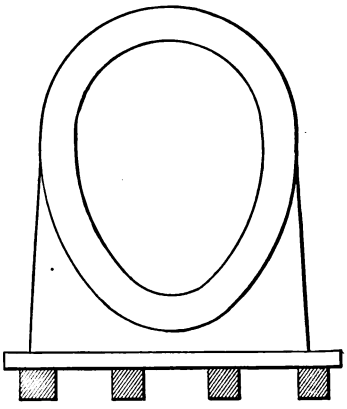


Fig. 24.



angles to the first, where there is any question of its stability, as in Fig. 23, or it may require longitudinal sleepers to

which a covering of heavy plank is spiked, as in Fig. 24, or even two courses of planking, according to the importance of the work. Or if the bottom is quite soft and yielding to some depth, and it is not considered expedient on account of the cost to excavate it to a hard bottom, then piling may become necessary driven to the hard bottom, or, indeed, if the bottom be beyond reach, still a good foundation may be had by a proper arrangement of piling; the frictional resistance of the latter and the stiffness imparted to the plank floor which rests on cross-sleepers on the head of the piles, which may be enveloped in concrete, will confer all needed stability. In this matter of artificial foundations, the engineer will require the exercise of his best judgment.

For pipe-sewers, the foundations will not require piling; by extending the breadth of the grillage and the depth of the concrete, all needed strength may be obtained. In wet bottoms where springs appear, various means may be resorted to for carrying off the subsoil water; but, as previously remarked, if the subsoil water be merely that due to local percolation, and not arising from springs fed from more extended areas, no special precautions are considered necessary beyond that required to remove the water during the construction of the sewer, that it may not interfere with laying the invert of the sewer, nor expose the cement used to the action of running water before it becomes properly indurated. To this end, in very springy ground, a small well or pit is excavated below the bottom of the trench to which the waters will drain, and the supply-pipe from the steam-pump will enter this well. In wet bottoms it has been largely the practice in some localities to put in an invert block of burnt clay or stone-ware, such as in the figure, not so much to serve as a permanent drain

(though this effect is claimed for it) as for convenience to the constructor in laying a good invert, the bricklayers being disposed to slight the joints of brickwork in such situations.

The use of these blocks, however, we cannot recommend, neither in wet bottoms nor in dry, for the reason that a *through* joint is the result at *a*, *a*, *a*, *a*, Fig. 25, which will scarcely, if ever, remain tight, but by settlement or otherwise, will ultimately permit the liquid of the sewage to break away, and besides losing thereby the scouring power of the liquid in removing the heavier portions of the sewage, also tend to poison the subsoil. The fact that the subsoil drains from sewers so built discharge sewage, should be a sufficient warning as to the use of these blocks. If the precaution be taken to use arch-moulded bricks for the inverts, or machine-cut brick, which are inexpensive, and in half-brick rings, with a proper oversight of the workman and the preparation of the cement, a much safer invert can be had than by the use of these blocks. In this connection the English practice may be noted, of building the invert of solid blocks, as in Fig. 26, the objection to which is the same as above stated in the use of open blocks, and the advantages of concentric half-brick rings without through joints apparent.

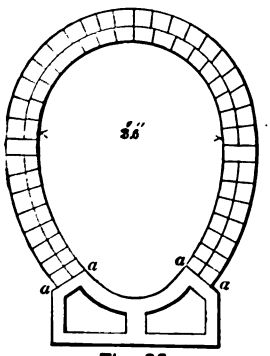


Fig. 25.

Where springs are encountered, means must be taken to leave an open sub-way for a permanent drainage of the bottom. For this purpose there are several methods dependent upon the volume of water to be dealt with, as in Fig. 27, where the longitudinal sleepers rest upon a bed of

broken stone, and are floored with heavy plank spiked to the sleepers, or as in Fig. 28, where the bottom of the trench is excavated to a depth sufficient to bed in broken

Fig. 26.

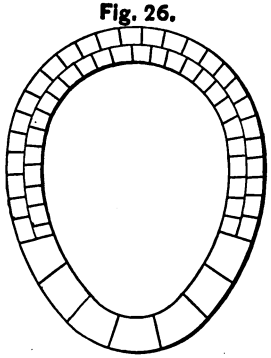


Fig. 26. *a*

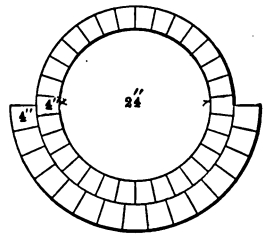


Fig. 27.

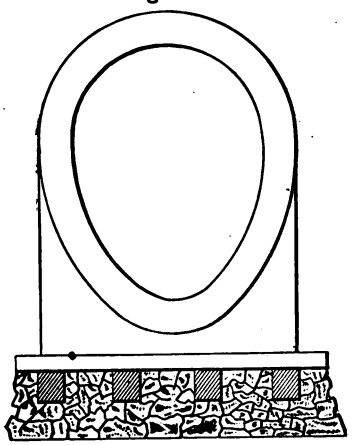
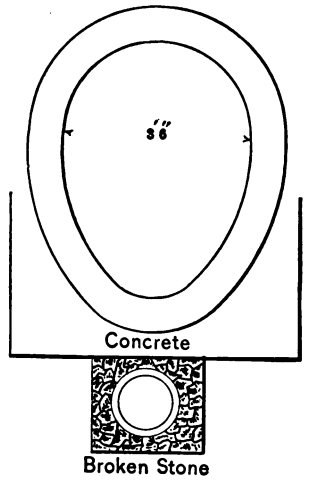


Fig. 28.



stone a pipe, either of stone-ware or cement, laid with open joints; that is to say, the spigot end of the pipe is inserted in its proper hub, but no cementing material is applied in order to the ready drainage into it.

In the construction of the smallest size of brick sewers used—that is to say, the equivalent of a circle of 20 or 24 inches in diameter—the thickness is usually a half-brick; but unless such sewers are enveloped in concrete, or the brick moulded or cut to suit the arch, they cannot be relied upon to retain the sewage, but it will be sure to pass into the subsoil to a greater or less extent. The idea that such leaks will, on the contrary, tend to drain the subsoil, is a fallacy in many cases, for the head of the subsoil water is very rarely greater than that in the sewer. Fig. 26*a* is a good method of meeting this. Sewers of from 3 feet in diameter and upwards to 5 feet, should, in ordinary depths of cutting, be a whole brick in thickness, laid in half-brick rings. The brick, in all cases, should be thoroughly wet before being laid, and with full joints of freshly-mixed cement; the joints struck flush on the inside, where they should never exceed one-quarter of an inch in thickness. For the larger sizes of sewers, the thickness will depend upon the plan to be carried out, and the circumstances which may control that plan. In the larger sizes of special design, the use of rubble stone laid in cement and faced with brick for the abutments of the arch, is usually found preferable on the score of economy to a construction wholly of brick. See Fig. 11.

After the completion of the brickwork and before the centres are struck, the back filling should proceed by carefully tamping the earth on each side as high as the spring of the arch, where it may be left until the closing of the arch, when the back filling should be carefully carried up equally on both sides. In laying pipe-sewers (if of stoneware of large size) it is preferable to use a sleeve rather than a bell and spigot, in order that the pipe shall not be supported merely at the ends when in place, and thus be

subjected to a cross-strain, but shall bear equally throughout its length, the earth being excavated to make room for the bell or sleeve.

The advantages of using a sleeve-pipe, Fig. 29, rather than a bell and spigot, consists in the ability thereby con-

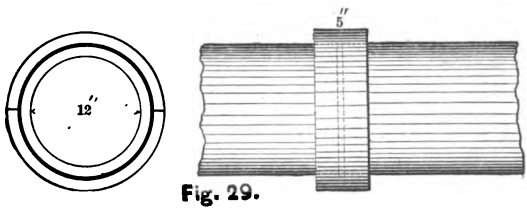


Fig. 29.

ferred of making a more perfect joint, by first setting the lower part of the sleeve, which is divided into three segments, and bedding the pipe upon it; and then bringing the adjoining pipe into contact, finish by cementing the upper parts of the sleeve into their places. This latter method also permits of taking out a single pipe if damaged, or for the insertion of a branch, if it becomes necessary, in a line of pipe-sewer already laid, without disturbing the joints of the adjoining pipe on either side, as would be the case were a bell and spigot pipe to be removed. In laying either description of pipe, the joints should be filled to excess with cement, and the superfluous cement or burr formed on the inside carefully removed with a scraper or swab. In the use of round pipe, it becomes necessary to tamp the back-filling under the pipe to give it the needed bearing throughout its length. The difficulty in effecting this properly, or the neglect to do so, results frequently in the ultimate splitting of the pipe after it has been in use, or rather it is only perceived then; when, upon re-opening the trench to make house connections, the effect of this neglect in giving the pipe a perfect bearing is conspicuous, and is frequently observable even with the best description of pipe.

This it is which renders the flat-bottomed cement-pipe, Figs. 30, 31, 32, a desirable substitute, and one which we have never known to fail from this cause. By placing a bed-plank lengthwise of the trench upon which the flat bottom of the cement-pipe rests, a very uniform bearing is obtained, which is a valuable feature towards insuring permanency. It is impossible to make a proper connection by cutting into a pipe, therefore all possible connections likely to be called for should be anticipated, and a branch pipe inserted during the construction of the work and capped with an earthen-ware cover laid in cement, and the location of all such branches recorded, otherwise the unexpected necessity arising for a new connection with the sewer, in the event of bell and spigot pipe having been used,

Fig. 30.

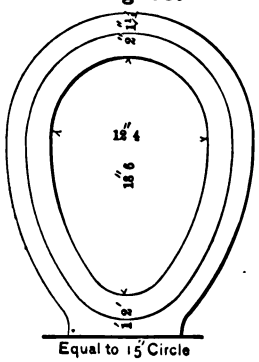


Fig. 31.

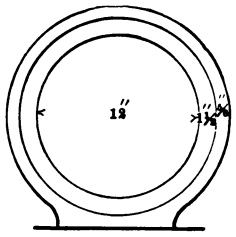
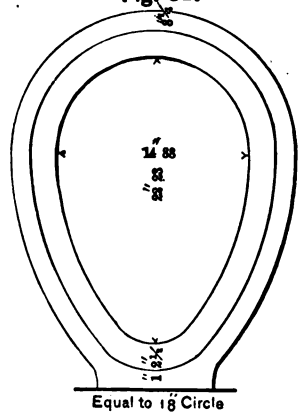


Fig. 32.



the joints and bearing of many of the pipes must be broken in removing a pipe, with the uncertainty at all events as to how far the disturbance may have extended.

Fig. 33.

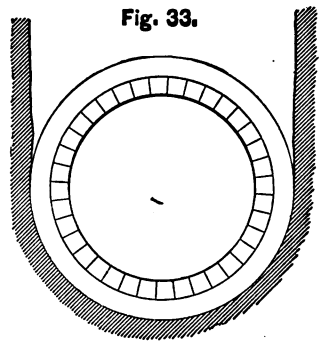


Fig. 33, combined brick and concrete, is indicated as in a firm bottom requiring no special preparation.

Again referring to the importance of all junctions with the sewer being made at an acute angle, etc., opening in the direction of the current, Fig. 37 (strange as it may seem, they are not unfrequently met with in the reverse position), and the curves laid with *curved* and not straight pipe; we would add, that the radius of junctions should be of as large radius as the locality will permit, and when of brick, worked with such care as to give this length of radius its best effect. Plates 39, 40, 41 and 42 will show these junctions in a brick sewer of 3 ft., and Pl. 43 and 43*a* of bell and spigot pipe sewers, which explain themselves. Fig. 37 shows in plan the junction of brick sewers of different dimensions, and also the pipe junction blocks or branches, which are built into the brickwork as it progresses for house connections, and which are capped with an earthen-ware cover until such time as the property owners may see fit to connect their houses with the sewer. Fig. 38 is the plan of a street crossing of the

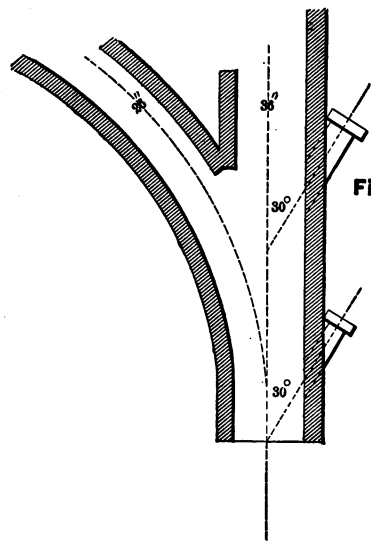


Fig. 37.

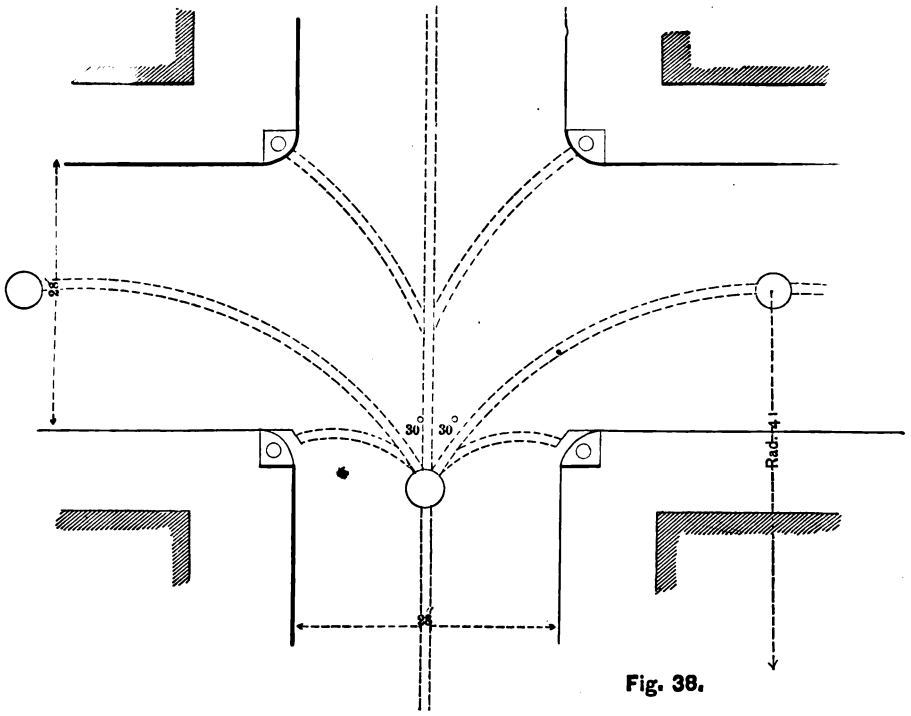


Fig. 38.

minimum dimensions, showing the curved junction of branch sewers, as also of shoots from the corner street-basins and the man-holes at the points of junction.

If the branches from the right and left in the above figure are of brick, as also the main sewer, they may be struck at a tangent by a shorter radius; but if wholly of pipe, the angle of junction cannot be worked at less than 30° as shown.

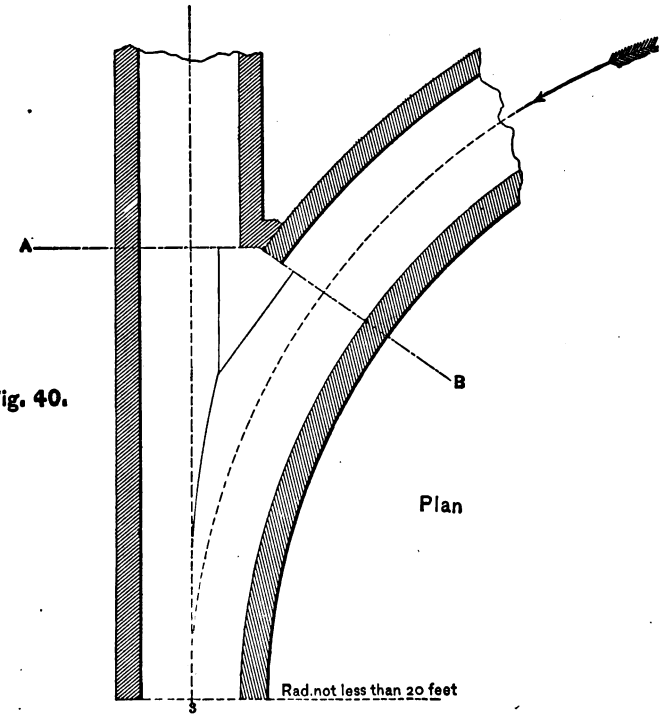
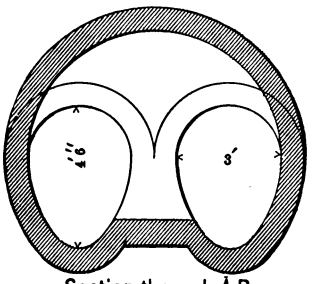


Fig. 40.

Fig. 39.



Section through A.B.

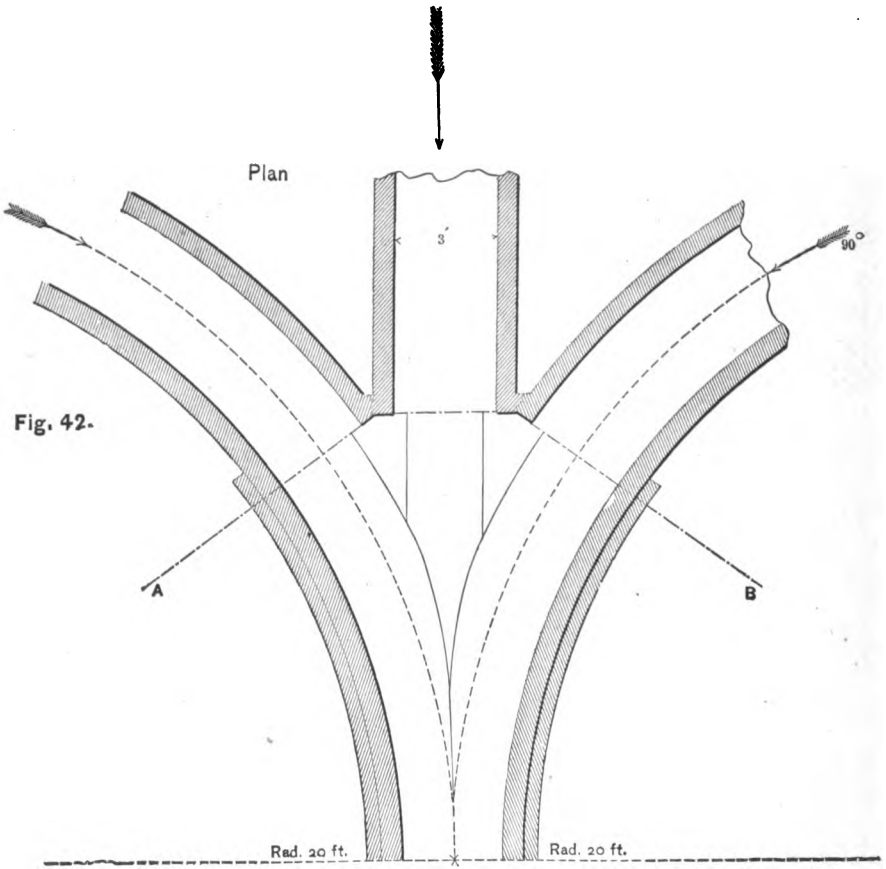


Fig. 42.

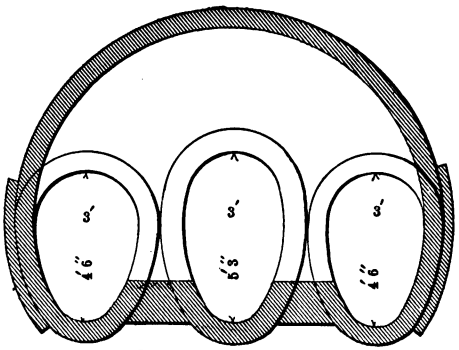


Fig. 41.

Section through A.B.

Fig. 43.

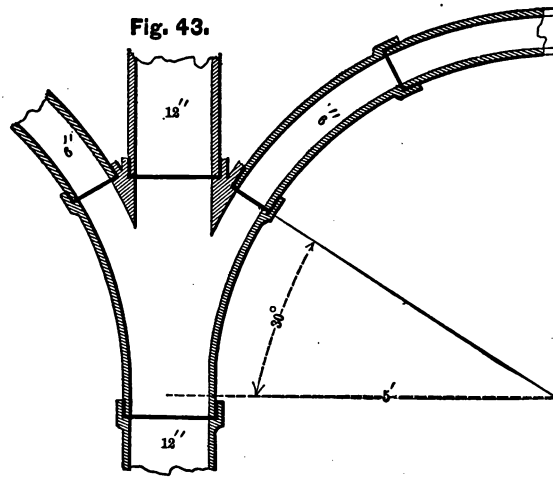
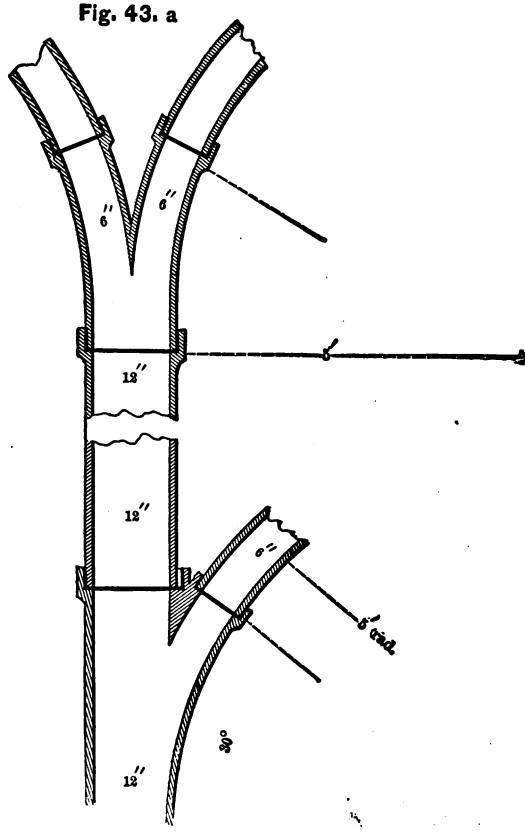


Fig. 43. a

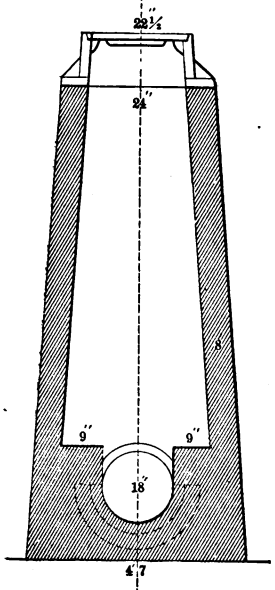


APPENDAGES TO SEWERS.

Man-holes.—In the line of the sewers, both main and laterals, with a view to a proper inspection of their working, and to furnish the means for cleansing and flushing out obstructions, as also for purposes of ventilation to be noted subsequently, it is necessary to construct man-holes at intervals of about 100 feet; the intervals can be greater on steep inclines. These man-holes consist of vertical brick shafts extending from the bottom of the sewer, where, in the case of small sewers and pipes it is elliptical in plan, being 3 by 4 feet in diameter, and in large brick sewers built into the top arch, and rising to the street-level, where it is circular, of about 2 feet in diameter, and capped with a cast-iron or granite frame, into which, flush with the street-grade, a heavy cast-iron cover drops into a circular groove made to receive it. Figs. 44, 45, 46, 47. These man-holes are one brick thick, and may have iron rods of one inch in diameter built into them to serve as steps, or dispensing with these can be entered by light ladders carried by the workmen. A man-hole should in all cases be placed at the junction of curves, or at any change of alignment, whether vertical or horizontal. By passing a light down any man-hole, observation from the next man-hole should show the character of any obstruction which may intervene.

And in the event of the formation of deposits which resists the scouring effect of the ordinary flow of the sewage, a pointed iron rod put together in lengths of about eight feet, with rake, shovel, brush, or any desirable tool screwed at the end, will suffice to stir up the material, when, by the operation of flushing, it will be swept to the outlet. It forms no part of the plan of sewers that this deposit be lifted by manual labor to the surface, hence the bottom of the

Fig. 44.



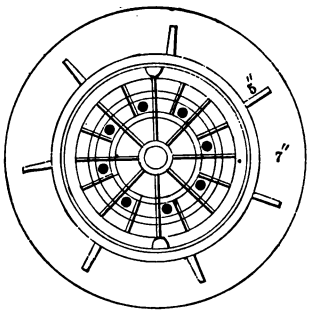


Fig. 47.

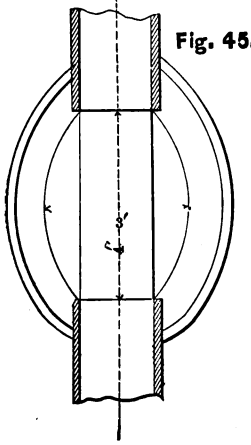


Fig. 45.

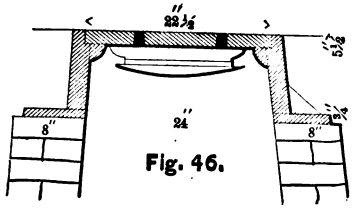


Fig. 46.

man-hole should be coincident in level and grade with that of the sewer itself in all cases, and by no means, as has been recommended, to form a catch-basin below the level of the sewer for the retention of the deposit. The latter method, wherever it has been adopted, has given great trouble from the accumulation of sewage in these basins giving rise to unwholesome exhalations. If the hydrant or fire-plug of the water-supply be convenient, nothing better can be had than to lead the water from it by a flexible hose furnished with a proper nozzle directly to the deposit; and whoever has witnessed the operation of hydraulic mining in California, or the effect of a stream of water from a fire-engine, will understand the value of a concentrated jet of water in removing anything less compact than cemented masonry.

If there be no hydrant with water-supply convenient, a movable tank on wheels conveying the water to the man-hole will answer a good purpose, by constructing a temporary dam of planks to hold back the water until a good head is obtained, when the sudden rush of the water will remove most obstructions likely to occur, if the precaution has been taken to stir up the deposit by the previous use of the jointed rod. Or if it be not convenient or desirable to use clean water; after the application of the jointed rod, and putting in the temporary dam, the collection of waste-water and sewage above the dam, suddenly set at liberty, will, if repeated at intervals, produce a very effectual flushing if the line and grades of the sewer are arranged in view of operating by means of the water-carriage system; but it will not flush a line of sewer of excessive cross-dimensions, or with abrupt angles, or changes of shape, or if it has been so long neglected that the deposit has become completely indurated. The facility of inspection offered by the occur-

rence of the man-holes at short intervals, leaves no excuse for the formation of any formidable obstruction. To facilitate the application of a movable plank dam, a 3-inch groove may be left in the brickwork of the invert of the large sewers under the man-hole shaft, but will be unnecessary in the pipe-sewers.

The expensive system of fixed valves or flushing gates, rendered necessary originally in England by the inadequacy of the water-supply, are not essential to the efficiency of a properly-constructed line of sewers in this country; and the ingenuity of the workmen charged with the flushing operations will always be able to provide a simple-working temporary plank dam which can be applied wherever required. One of the simplest of the permanent iron-gates for flushing is shown in Figs. 48, 49, 50, and, as will be seen, requires a side chamber to be built in the sewer for its efficient operation; Fig. 50 is the sewer and chamber in plan; Fig. 48 is a section of the sewer showing the elevation of the gate, which is hung in an iron frame set into the brickwork and opens horizontally, and is but half the height of the sewer; and Fig. 49 is a longitudinal section and elevation on the axis of the sewer.

The cast-iron cover shown in Fig. 47 is perforated with holes as shown, each not less than $1\frac{1}{4}$ inches in diameter at the face, and $1\frac{1}{2}$ inches below or even more, to prevent small obstructions lodging in the opening. If the streets are not paved, or liable to being covered with sand or gravel, a sheet-iron pan hung by three wires will catch all such material, and permit of its removal at intervals by hand (the cut, Fig. 46, does not show clearly the simple attachment of this pan). In the English system of ventilation the man-hole cover is solid, and a side chamber is built alongside of the man-hole shaft with which it connects by a pipe, and

its cover is perforated, permitting the gases from the sewer, either chemically treated or otherwise, to escape thereby, and the refuse from the street to be collected in this chamber. But it is a needless complication, and the same purpose can be effected as we propose by means of the suspended tray.

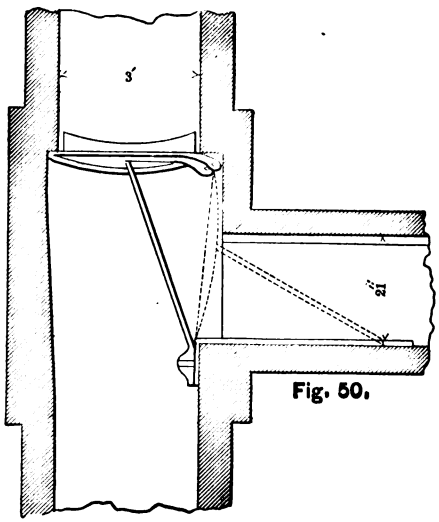


Fig. 50.

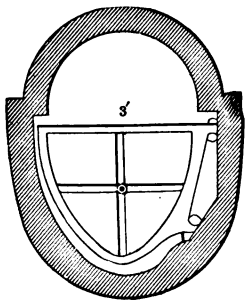


Fig. 48.

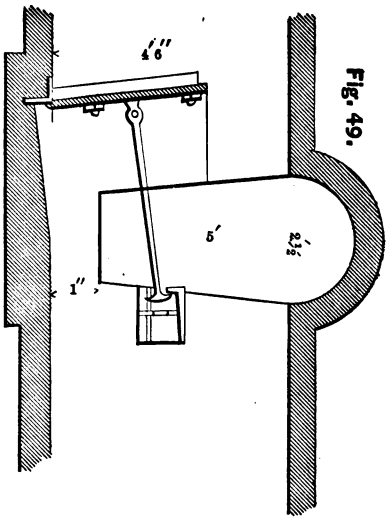


Fig. 49.

STREET-BASINS.

At the corners of the streets, and sometimes on steep inclines intermediately in the line of gutters, basins of brick masonry with granite or cast-iron covers are built to receive the run of the gutters and street drainage and convey it to the sewers. There are various shapes and dimensions given to these, differing but little in principle or action. They need not be large if the streets are well swept and a proper police of the basins maintained; but the neglect of this, and the accumulations in the gutters of the detritus of the streets which find their way into them during storms, renders it necessary that they should be of sufficient capacity to avoid being overflowed in a single storm, and a capacity of at least a cubic yard of solids becomes desirable below the lowest point of their trap. The style of construction shown in Figs. 51, 52, 53, is as simple and efficient as any in use, and is elliptical in plan, 4½ by 3½ feet, and about 8 feet in depth below the level of the foot pavement. The foundation should be well and tightly laid, and, if need be, in concrete; for the retention of the liquid is equally important in this case as in the sewers, and for convenience in cleaning, the bottom should be, if possible, a single stone or flag, as should be the trap stone *t*, which is built into the side walls. We consider this the simplest and most effective method of trapping the

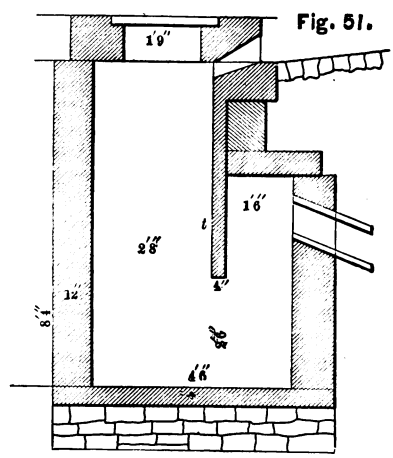


Fig. 51.

discharge pipe, although the method adopted by Mr. Shedd in Providence of dispensing with the flag-stone *t*, Figs. 51, 52, and in lieu of it placing a hinged hood over the open-

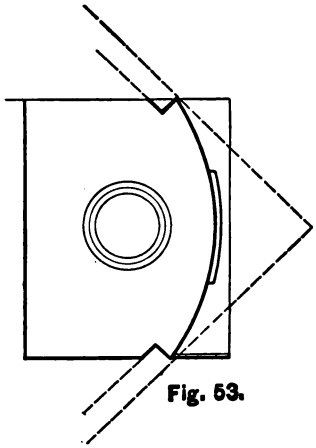


Fig. 53.

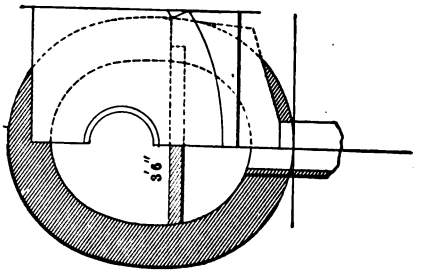


Fig. 52.

ing into the shoot to the sewer, either of iron or stone-ware, and making a joint of cement around it, which can be broken and renewed if the occasion requires, has stood the test of several years experience, and has some advantages possibly. See Figs. 54, 55, 56.

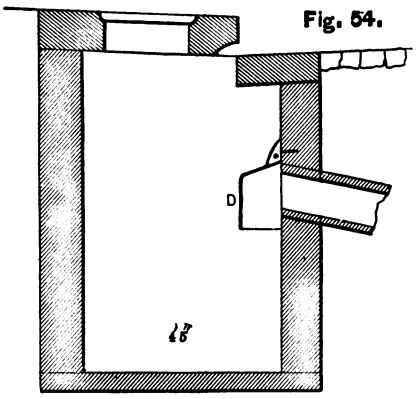


Fig. 54.

We consider that during excessive rains too much water may be carried to the basins, and the discharge-pipe from them into the sewers being usually a 12-inch pipe, permits of a body of water being suddenly thrown into the sewer far beyond its capacity, and for a short time occasioning overflows, which would occasion much less inconvenience

if allowed to be on the streets or in the gutters. The fall from the basin to the sewer is rarely less than 7 feet in say 25 feet of distance, and in reality a 3-inch pipe would, under the circumstances, discharge into the sewer more than an inch of rain falling in an hour over 750 feet of street; hence, if this connecting pipe be made of 6 inches

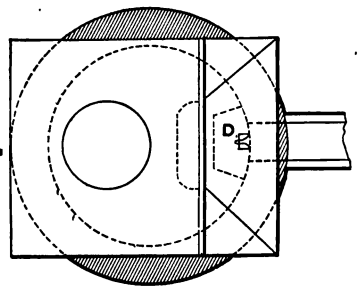


Fig. 55.

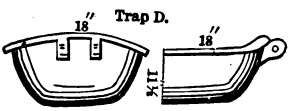
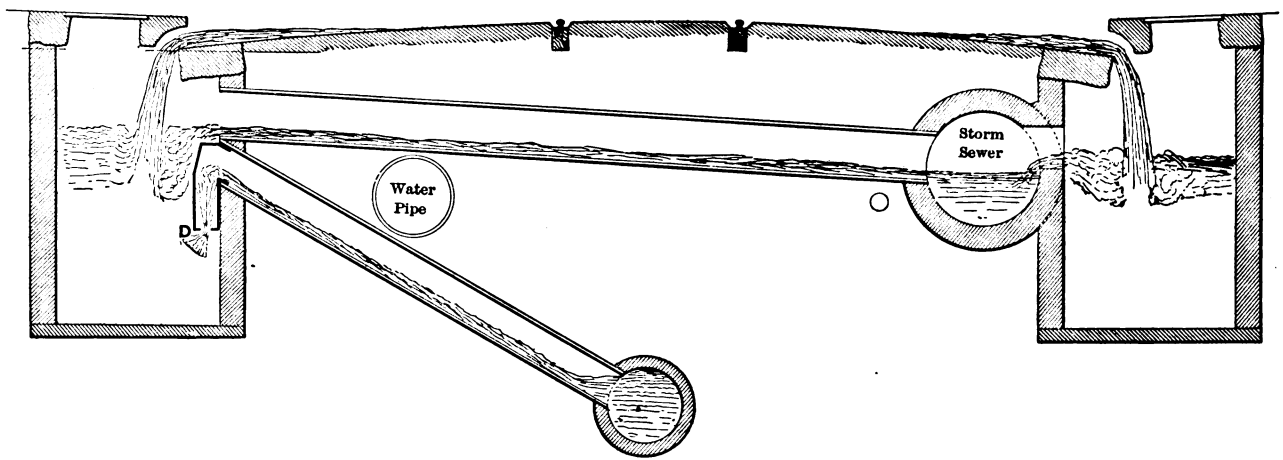


Fig. 56.

instead of 12, it would pass two or three times more water than the sewer could carry in the same time. But the best method of restricting the amount of water entering the sewer by means of the street basins to the amount which, for the distance drained, is estimated as within the capacity of the sewers, is as yet undetermined. It is desirable that some means be used to throttle, as it were, the discharge into the sewer, through the street-basin, either by restricting the dimensions at the street-grating or that at the connecting-pipe. A method of effecting this in connection with a storm-sewer has been adopted in Providence, R. I., which Mr. Grey, the city engineer, states as quite efficient. It consists, Fig. 57, in throttling the opening under the trap *D* in the street-basin (which is a cast-iron hood shown in section at Fig. 54, in plan in Fig. 55, and in elevation detached in Fig. 56) by an adjustable iron bottom, leaving an aperture of such dimensions as, with the head of water in the street-basin, only so much is discharged into the

Fig. 57.



Scale 1 in. = 5 ft.

The trap *D* is similar to the same trap shown in Figs. 54, 55, 56, with the exception of a bottom plate of iron, which admits of adjusting the size of the opening to the required discharge instead of the bottom being entirely open.

main sewer as it can carry off—all above that is conveyed by a branch-pipe into the storm-sewer.

TIDE-VALVES AND TANK-SEWERS.

In a former part of this work, when referring to the little dependence to be placed upon self-acting valves below the tide-level, towards preventing the sewage backing into the house-drains, reference was had more particularly to localities where a thorough and complete drainage could be had to the premises at a higher level, but where the attempt had been made to drain basements or cellars below high tide on the presumed ability to shut out back sewage by self-acting valves. In localities which do not admit of a higher level being assumed, and where the necessities of the locality require that the house-drain shall be below high tide, a certain degree of safety may be had by closing the house connection with a flap, either of stone-ware or of iron, and retaining the sewage until the lowering of the level in the main sewer, either by the fall of the tide or the contents having been lowered by the operation of pumping. Implicit dependence, however, must not be placed upon the certain working of this flap. A small obstruction may interfere to prevent it, but it is usually for a limited length of time, and is the only expedient, probably, which admits of general application in such localities. They are thus applicable to house-drains which discharge into tide-locked sewers, or into tank sewers, but they need never be used in the hope of preventing sewer-*gas* from entering the house-drains; they will prove wholly inoperative for such purpose, though not unfrequently recommended as a suitable means. Figs. 58, 59, show two of the simplest forms of flaps, the one hung with shackels, the other a plain hinge, the first of cast-

iron, the latter of stone-ware, and they should be ground to fit as closely as possible. The same principle may be and is extended to large brick sewers, but with greater attention

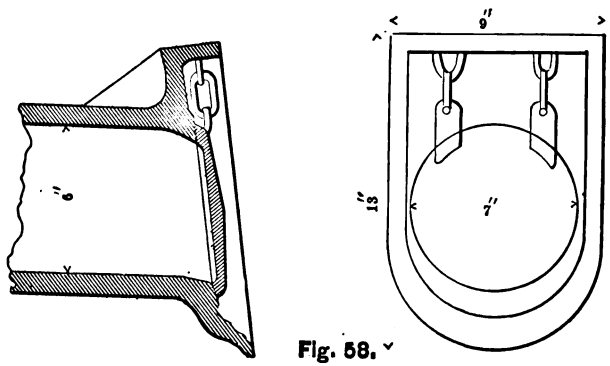


Fig. 58.
Galvanized Cast Iron Valve

being paid to the hanging of the flap, which should not be by a shackle but by double links and hinges.

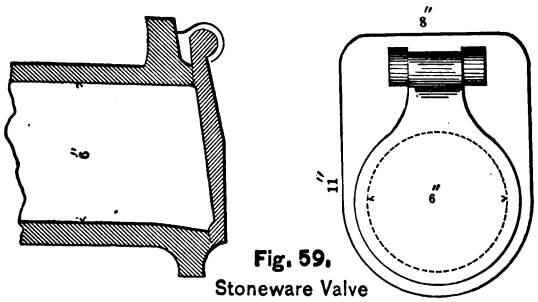


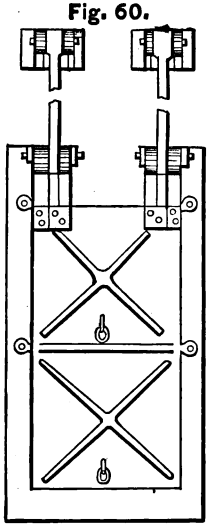
Fig. 59.
Stoneware Valve

Tank Sewers.—These should be provided for all tide-locked sewers; and if the surface-waters can be carried off by storm-water overflows, to be subsequently noted, they form a convenient method of storing the sewage, and consist simply in an enlargement of the dimensions of the main sewer for such distance as shall suffice to hold the house-sewage discharge during the time the gates of the main sewer below are closed by the tide. Their dimensions will

depend upon a careful computation of the needs of the district under consideration, and the sewer above should also be provided with an iron flap valve at its junction with the tank-sewer.

The tide-gates for automatic action at the outlets of the tide-locked sewers may be made of wood or iron; if of wood, they are usually similar to an ordinary lock-gate on a canal, made in two leaves, hung to vertical posts on each side of the gate-chambers, and meeting on a mitre sill at an angle of about 135°. The chamber in which the gates are placed is large enough to admit of two pairs in the length of the chamber, to provide for any contingency, and admit of occasional repairs to either. Instead of the horizontal lock-gates, they may be made of two flaps, one above the other in the same frame, the flaps hanging from a horizontal axis and opening with a vertical movement. In this

Fig. 60.



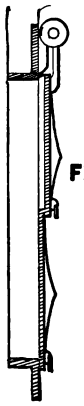


Fig. 60.a

case the gates should be of iron, and are much to be preferred to the timber gates. Figs. 60, 61 and 62 show the

arrangement of these gates. Fig. 61 is the frame set in the masonry; Fig. 62 is the lower gate, the upper, Fig. 62*a*, represented as removed; Fig. 60, the method of hanging. Both flaps are hung from the same bracket by links, and the upper flap, while bearing upon the lower, admits of opening independently of it, by which means the discharge of sewage may commence earlier than it otherwise would.

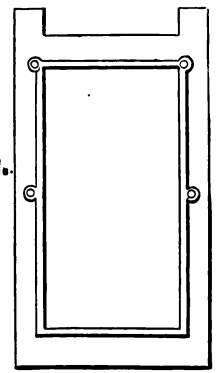


Fig. 61.

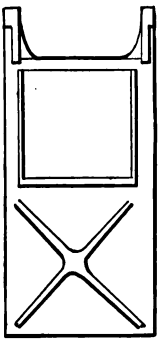


Fig. 62.

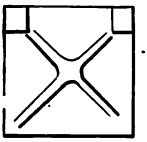


Fig. 62.*a*

These gates may be made either of wrought or cast iron. The latter resists better the action of salt water; the shackles, nuts, screws, etc., being of wrought iron, and the eyes of the hinges bushed with gun-metal. The bearing faces of the flaps should be planed and ground true; and it would be preferable that the bearing surfaces throughout should be of gun-metal, and would in the end prove economical. The same necessity exists for a double pair of gates in each gate-chamber, as in the case of wooden gates, that in the event of any accident happening to one and preventing its closing properly and excluding the rising tide, the other can be relied upon.

Penstocks are sometimes rendered necessary in connection with reservoirs for sewage. These are simply gates located as the tide-gates in masonry chambers, but instead

of being self-acting, are operated by power, and consist of a vertical iron frame secured to the masonry, within which iron gates slide, operated from above by various methods, such as chains and drums, worm-wheels, screws, or other gearing, and with counter-weights. By these means the tide can be shut off at pleasure, or currents of sewage diverted into other or various lines of flowage. Their use is special, and the principle of their construction and action is similar to the ordinary stop-cocks, used in water distribution—one of the simplest forms is shown, Figs. 63, 64,

Fig. 63.

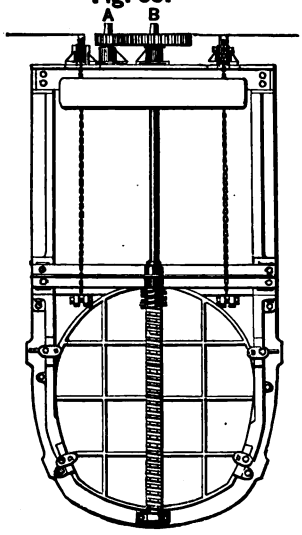
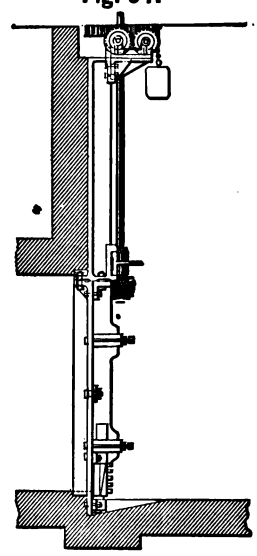


Fig. 64.



for a large circular sewer worked by a worm-wheel with counter-weights, Figs. 65, 66, representing the gate for an oval sewer with gearing and counterpoise. While for ordinary gravity works the penstock is rarely required, it forms an indispensable adjunct to a system of sewerage where the sewage is collected into reservoirs for distribution

to different outlets, or where pumping is resorted to for its movement.

Fig. 65.

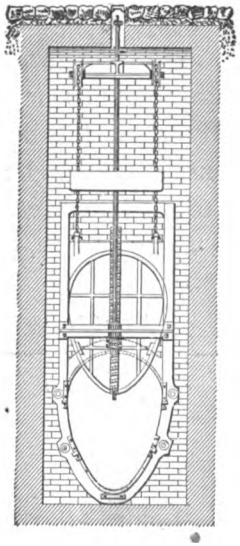
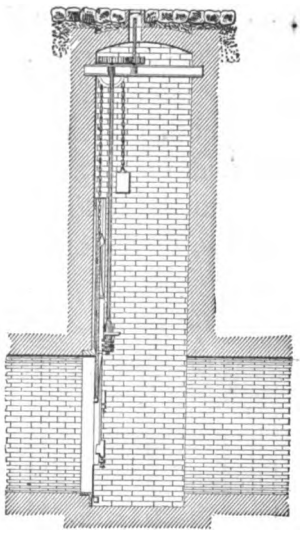


Fig. 66.



STORM OR OVERFLOW SEWERS.

We have assumed that provision for an inch of rain in one hour is all that need be provided for in this climate; and the motives for confining the dimensions of the sewers to as small sectional area as possible consistent with efficiency, and aside from any consideration of the cost of construction, has been already pointed out. It is undeniable, however, that heavier rains than we have provided for do occur, and in some localities these storm overflows may be attended with inconvenience which it is desirable to obviate; and to this end, what are called storm or overflow sewers are introduced, which may at the same time be used for the purpose of receiving ordinary sewage, but more frequently their use is confined to the discharge of storm-

waters alone. There is an ingenious device suggested to effect this, whereby the ordinary run of sewage shall drop through an opening into a lower line of conduit, and the storm-waters with a higher velocity is expected to leap over the opening and discharge itself elsewhere. This idea has been applied on a line of water supply to separate the turbid from the clean water, but is scarcely applicable to city sewers, although recommended by some writers. Fig. 68 represents it, in which the ordinary flow of sewage is expected to drop into the service main *B*, which is necessarily built at a lower level, but the deeper and more violent storm-discharge will follow the conduit *A* to its outlet, *S* representing the level of storm-discharge; *O*, the level of ordinary run of sewage. There may be localities where such a device, if attended with some apparatus to graduate the opening, and under intelligent supervision, would be attended with some advantages, but the circumstances which would favor their use will rarely be found to obtain in city sewerage works. A better arrangement to the same end is shown in Figs. 69, 69*a*, where on a line of sewer likely to be gorged by excessive rains an opportunity occurs for withdrawing part of the flow when running full, and carrying it by a shorter line to the outlet. This consists in making an opening or weir in the side of the sewer, which will permit the withdrawal of a portion of its waters and thus prevent its being gorged; or, in other words, it is providing several outlets instead of one for the storm-waters of a given sewer. By

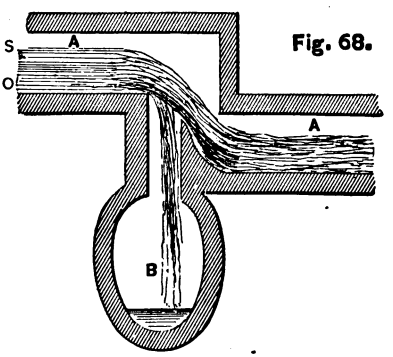


Fig. 68.

repeating this at intervals as the locality may favor, all needed relief may be afforded to the sewer. In the case of a line of sewer seeking an outlet by crossing an existing sewer at right-angles and on the same level, a modification

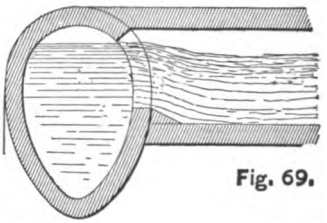


Fig. 69.

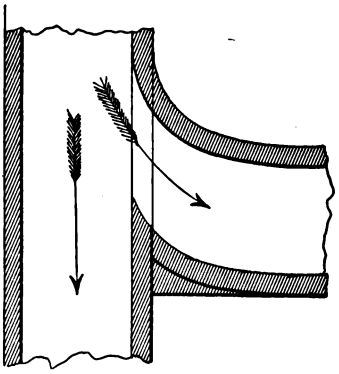


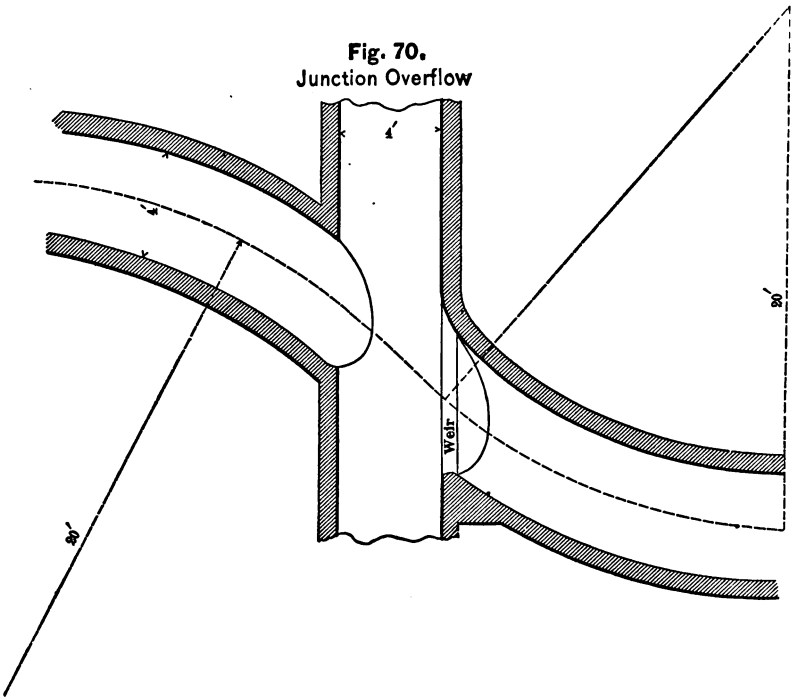
Fig. 69.a

of the same plan, as shown in Fig. 70, will answer a good purpose. It will be observed that the sewers do not cross at right-angles, but the crossing sewer enters by a curve of at least 20 feet radius, and the tangent to this curve prolonged indicates the position of the continuation of the crossing sewer, which will regain its true direction by a reverse curve.

INTERCEPTING SEWERS.

The principle of interception referred to, page 22, is so obvious that it requires no discussion. In the main drain-

Fig. 70.
Junction Overflow



age works of London, the principle has been developed upon such a scale that a study of it will well repay the engineer, and no apology is needed for introducing under this head the greater part of a most interesting paper read before the Institution of Civil Engineers London, by its engineer, now Sir Joseph Bazelgette. The reader is referred to that paper in the Appendix, as also to the Map of the London Intercepting Sewer System.

CHAPTER IV.

VENTILATION.

MUCH needless discussion has been had upon the arrangements essential to a proper ventilation of sewers, and many expensive expedients have been resorted to, to effect what will take care of itself under a proper system of sewer construction, without other means being resorted to than such as are called for in order to secure the efficient action of the water carriage system.

The theory of this system, as already shown, consists in so restricting the dimensions of the sewers, and having such regard to the location and principles of their construction, that the water-supply shall suffice to remove from the sites of dwellings all refuse which properly belongs to the sewer-discharge, and conveying it at once to the outlet, or delivering it at the outlet at the farthest but a few hours after its formation. If this could be effected in all cases, even within six hours after its discharge into the sewer, or even in twelve hours, it will be apparent that, with the current which a liberal water-supply will offer, no time would be given for dangerous decomposition to take place; but unfortunately this self-cleansing process is not complete at all times. No system of sewerage as constructed, is so perfect a machine as to operate itself with precision, and yet it is usually left uncared for until some unforeseen obstacle intervenes to its prompt action—the obstruction increases, stagnant deposits take place, decomposition sets in, dangerous gases are evolved, and special ventilation is called for to remove them,

while the authorities are engaged in removing the obstruction which, under a proper supervision, never would have taken place. But as we have to deal with things as they are, we admit that offensive gases are generated in the sewers, but we are satisfied that the *bad smells* are a positive benefit, for while the causes for the smells alone never can exist to such an extent as to produce mischief, they give a timely warning as to what is going on within, so that the really deleterious compound which sometimes accompanies these gases, and which is in itself destitute of odor, will receive an attention which otherwise it would not have had.

Sewer-Gas.—In the decomposition of animal and vegetable matters in sewers, together with the gases which, when combined in certain proportions, go to make the atmosphere, viz., oxygen and nitrogen, there are other well known gases present. There is carbonic acid, the heaviest known gas (the choke-damp of the mines), marsh-gas (seen in the will-o'-the-wisp), and other compounds of carbon and hydrogen, including what the miners call *fire-damp*, also ammonia, and its compounds with sulphur and carbon, sulphuretted hydrogen (known by the smell of decayed eggs), and carbonic oxide. None of these gases, although some of them when sufficiently concentrated are deadly poisons, notably carbonic acid, sulphuretted hydrogen, and carbonic oxide, yet none of them will produce the effects which we are accustomed to believe and indeed *know* will at times be produced by breathing the emanations from foul sewers and drains. In the case of poisoning by any of the above named gases the effect is confined to the subject, and he is entirely incapable of communicating it to others; but there is something else in sewer-gas, necessary to produce what we call *filth diseases*, and these diseases are capable of indefinite extension from patient to patient, thus distinguishing them from any known gas-poisoning.

Indeed it is questionable whether this poisonous substance, which it has been proposed to call for lack of a better name "organic vapor," be an actual gas, from the fact that it deposits itself upon solid bodies, such as the walls of a room, or on clothing, although the air of the former may have been repeatedly renewed and the latter well shaken and ventilated. What it is precisely, chemists cannot inform us. No analysis yet devised is subtile enough to detect it. It does not in general render its presence known by any sensibly unpleasant smell. It accompanies the decomposition of animal and vegetable matter, and with the known gases above stated, is what we call *sewer-gas*. This gas is not of itself, according to Prof. Nichols, either inflammable or explosive; illuminating gas may *leak* into the sewers in sufficient quantity to be explosive; his analysis, extended for many months in air from a tide-locked sewer, failed to show, although carbonic acid was largely present, either sulphuretted hydrogen or other gas of decomposition, in sufficient quantities to admit of expression in figures;* and it has become well settled,

* From Report of Prof. Nichols of Mass. Institute of Technology on Sewer-air:

TABLE.—EXAMINATION OF GASES FROM DECOMPOSING SEWAGE-MATTER.

[Results expressed in percentages.]

AUTHORITY.	Marsh Gas. (CH_4)	Carbonic oxide. (CO)	Carbonic acid. (CO_2)	Sulphuretted Hydrogen. (SH_2)	Nitrogen.	
R. Angus Smith	88.81	....	5.84	....	5.35	Gases evolved from sewage-matter in the Medlock (Eng.). (R. Angus Smith, Disinfectants and Disinfection. Edinburgh, 1869, p. 25.)
Dr. Letheby ...	73.83	....	15.90	0.08	10.19	Gases evolved from sewage decomposing in the absence of air. (Quoted from Parkes' Hygiene, p. 103.)
Durand-Claye .	72.88	2.54	13.30	6.70	4.58[1]	Gases evolved by decomposing sewage mud in the Seine. (Assainissement de la Seine, Paris, 1876. Deuxième partie. Annexes, p. 85.)

[1] And other gases.

TABLE II.—EXAMINATION OF SEWER-AIR.

[Results expressed in percentages.]

Date.	Authority.	Locality.	Oxygen.	Nitrogen.	Carbonic Acid.	Sulphuretted Hydrogen.	Marsh Gas. (CH_4)	Ammonia.	
182(?)	Gaultier de Claubry ...	Paris	13.79	81.21	2.01	2.99	.....	.....	Air in a choked sewer. (Quoted from Parent-Duchâtelet, "Essai sur les cloaques," Paris, 1824, p. 223.)
1829	Gaultier de Claubry ...	Paris	17.4	.....	.....	.....	.....	.....	Smallest amount in any one of the 19 samples examined.
					3.4	.....	.....	.....	Largest " " " " " " " " " " "
					.....	1.25	.....	.....	" " " " " " " " " " "
					2.3	0.81	.....	.....	Mean amount in 19 samples. (Quoted from Parkes' Hygiene, p. 104.)
1858	Dr. Letheby	London	19.51	79.96	0.53	traces.	traces.	more than traces.	(Quoted from Parkes' Hygiene, p. 104. Latham, San. Engineering, p. 205.)
1867	Dr. W. A. Miller.... ..	London	.....	.....	0.11	.....	.....	.....	Mean of 18 samples. Sewer without charcoal ventilators.
			20.71	.....	.....	.....	.....	.....	" " 6 " " " " "
			20.79	.....	0.13	0	.....	.....	" " ? " " with " "
					0.31	.....	.....	.....	" " 6 " (another sewer) without " "
					0.25	.....	.....	.....	" " 24 " " " with " "
			20.70	.....	.....	0	.....	.....	" " 4 " " " " " " (Quoted from Chemical News XVII, [1868] p. 156.)
1870	Dr. W. J. Russell	Paddington, London.	20.79	78.81	0.40	.....	.....	traces.	(Quoted from Br. Assoc. Rep. 1870.)
1871	J. J. Nicholson.....	Sunderland, Eng....	18.44	81.10	0.55	traces.	.....	traces.	(Quoted from Proc. Munic. & San. Engineers, I [1873-74], p. 50.)
1873	" "	" "	19.33	80.35	0.23	.....	.....		
1876	Drs. Wolffhügel & Bleetz.	Munich	*	.....	0.33	.....	.....	.....	Mean of sewer examinations in three sewers.
			*	.....	0.40	.....	.....	.....	Maximum of " " " " "
									(Quoted from II Bericht der Commission für Wasserversorgung, etc., Munich, 1877, p. 50.)
1878		Berkly Street Sewer, Boston	20.75	79.	2.09	.....	.....	.....	Mean of 25 samples.
		Normal air	20.96	79.	.04	.....	.....	.....	

* Not essentially different from ordinary air.

that the poisonous gases so called, are not the sources of danger in sewer-air.

Whether the chemical or germ theory of the propagation of disease from sewer-gas be accepted as true, we only know that its danger to human life is lessened, if not entirely removed, by an extreme dilution with fresh air, and this dilution is what we understand by ventilation. It appears, however, that to be efficacious, this dilution should take place in the birth-place of the sewer-gas, for the same degree of dilution after the sewer-gas has entered a dwelling is not so satisfactory in its results, and this apparent anomaly is explicable if the germ theory of disease be accepted as true. In the decay of organic infusions, the resulting compounds are presumably the food by which these low organisms, which appear in such multitudes, are nourished and developed; so in the decaying gases in sewers, organic vapors are generated by the breaking up of more complex molecules, and though in comparatively small quantities, they may yet be sufficient to nourish floating organisms, and if these floating organisms, or the source of disease, feed and multiply in the decaying organic vapor of sewers, where the surroundings are favorable, the dilution by fresh air, or the resulting oxydation, may so impair the conditions of this food as to prevent their dangerous multiplication, and so lessen the number that may be carried into a dwelling; but if once there as living disease-germs, no change in their condition is to be anticipated.

It is supposed that the sewer-air in its effect upon the health of human beings, aside from the germs of disease which may be floating therein, has a chemical action as of known poisons, which, though too weak to kill outright, may yet lower the tone of health, and thereby render the system favorable to the reception and development of dis-

ease germs. It would be interesting to go into this matter of the germ theory of disease, at least so far as to indicate the extent and bearing of the facts which are considered to sustain it; but it is foreign to the purpose of this work, and the author cannot lay claim to having made any original investigations in this direction, but would refer the reader to a paper by Prof. F. A. P. Barnard in the published Report of the American Public Health Association of New York, 1873.

It is enough for our present purpose to know, that dilution by fresh air, if it does not destroy the seeds of disease brought by sewer-gas, whatever they may be, it has a tendency to interrupt and render harmless their action on human organisms, providing that the sanitary surroundings are otherwise rendered favorable. The currents of air within the sewers, the control of which constitutes their efficient ventilation, are effected by the following forces or circumstances:

First.—Heat.—This is an important element in all ventilation, and owing to the intermittent introduction of hot and cold liquids into sewers, and the heat generated by decomposition, is extremely variable in its extent and effects, daily creating repeated expansions and condensations with the changing currents of air due to their action. The difference of temperature between the external atmosphere and that within the sewers is a force always at work tending to effect this ventilation; and if allowed free action, it will accomplish all that is needed.

The following table, compiled from observations of Mr. Wm. Haywood, shows the mean temperature, Fahrenheit, in the London sewers.

	Temperature of External Air in Shade.			Temperature of Sewer Air.			Mean Temperature of Sewers.	
	Highest.	Lowest.	Mean.	Highest.	Lowest.	Mean.	Above External Air.	Below External Air.
Summer.....	72	55	65.	68	56	62.	....	3.12
Winter.....	34	30	32.4	52	40	44.	11.6	....
Spring.....	61	46	52.5	59	48	52.5	.06	....
Fall	68	48	60.	70	53	63.	3.07	....

From which it will be observed that the temperature can rarely be the same in the sewer as in the open air. Even in the spring of the year the variation in the temperature of the open air between day and night will be sufficient to produce air-currents, and for the entire year the average temperature of the sewer is above that of the external atmosphere.

Air increases in volume .00204 for every increase in temperature of 1° Fahr., and the openings in the sewer are the channels through which the warmer air by its increase in bulk tends to escape into the colder and heavier surroundings, or, under certain circumstances, local currents may take place in a reverse direction.

Second.—The ebb and flow of the sewage is constantly taking place, caused by the influx and withdrawal of large volumes of waste water within the sewers, and has an effect on the air-currents, as the rise of the contents within the sewers must expel in some direction whatever air or gases previously occupied the space.

Third.—The position of the outfall of the sewer relatively to the direction of the prevailing winds, affects the currents within the sewer, as does also the level of the discharge, and whether the outlet is sealed or not by the rise of the tide, when the outlet is in a tidal basin. In the latter case, while tide-locked and during the flood-tide, the sewage continually increasing in quantity within the sewer, the con-

tained gases will of course be expelled, and at ebb tide, as the sewer discharges, fresh air will be drawn into the sewer. Wind entering the mouth of the sewer is not objectionable where a natural ventilation such as we shall propose subsists, but it might interfere materially with any artificial method of ventilation. As modifying the forces operating within a sewer, notice should be taken of the property known as the "law of diffusion," by which gases are diffused one within the other, having regard to their respective densities only so far as it affects the rapidity of this action; the rate of diffusion between gases being inversely as the square root of their respective densities. By this law, light gases descend and heavy gases rise. Carbonic acid, the heaviest of known gases, is found in its normal proportion, as regards the constituents of the atmosphere, at the greatest height to which man has ever ascended.

On grades of steep inclination, and indeed to a certain extent on all slopes, the higher temperature of the sewer air above that of the external air, may promote the entrance of the latter at the lower points of the system and its escape at the upper, acting similarly to a chimney or vertical shaft, and governed by the same laws of pneumatics. The upward force or draft in a chimney lies in the difference in weight between the column of heated air in the shaft and a similar column of the external air. If we ascertain the difference in height in feet between two columns of air of equal weight in communication with each other, one being heated and the other at the temperature of the atmosphere, the air will flow in the direction of the heated column with a velocity equal to that which a heavy body will acquire in falling freely through this difference in height between the two columns. Calling this difference (d), and this velocity in feet per second is expressed by $v = \sqrt{2dg}$. Air increases

in bulk $\frac{1}{480}$th part for each degree of increase in temperature. If we multiply the expansion caused by 1° of heat by the number of degrees the temperature is raised (or the difference $t - t'$ between the temperature of the two columns), and by the height of the heated column (h) we will have the value of d, or the difference of height in feet between two columns of air of different densities but of the same weight, or $d = h.00204\ (t - t')$ = height of the column of air which produces motion. Substituting this in the equation of velocity, we have velocity in feet per second, $v = \sqrt{2gh0.00204(t - t')}$, and the pressure on a given area may be found by the proportion it bears to a square foot, a cubic foot of air at 60 F. and bar. 30 being taken at 539 grains avoirdupois. If the shaft were one square foot in area, then the pressure would be $(t - t')h0.000157$ in pounds. The whole of the above is purely theoretical, and in practice a large allowance must be made for contraction of the fluid vein and frictional resistance—and this contraction cannot, as in the case of liquids, admit of direct observation.

The effort to ventilate sewers, either by special machines or chemical reagents, have been more conspicuous in the older cities of Europe, where the existence of narrow streets and mixed systems of small and large sewers render the imperfections of ventilation more obvious and more difficult to remedy. Of the efforts to remove foul gases from the sewer by exhaustion, that by means of fans driven by steam-power seemed to promise success (to its projectors), but on trial it has proved otherwise; so also has the method by means of shafts with furnaces below. The attempt has been made to utilize the chimneys of manufactories to this end, but unsuccessfully; also to lead all the products of combustion in dwellings and factories through the sewers

to large chimneys, and thus to draw off all the foul gases; but all these efforts appear to have been based upon the erroneous supposition that the principles of mine ventilation could be applicable to sewer ventilation, whereas the varying position and extent of openings in the branches may become so great that neither by the method of forcing or exhausting could power be had sufficient to effect ventilation in sewers save at a very great expense of fuel. Special pipes have been laid from the sewers up the external walls of buildings in hopes of effecting a natural ventilation, and a screw-ventilating apparatus has been affixed to pipes so placed with a view to extract mechanically the gases within. It has been suggested to use the lamp-posts as ventilators, and also the street gas-posts—the combustion of the gas day and night, it was claimed, would effect ventilation. The steam-jet has been proposed, fully tested, and abandoned.

In all these examples, the proposers have lost sight of the enormous velocity which becomes necessary in one part of a system of sewers, in proximity to the power employed, in order that the velocity requisite for efficient ventilation should be extended to the outer boundaries. For instance: The branches and laterals which supply the main-sewers ramify into a net-work of small drains, ending in the waste-pipe from a dwelling. The combined area of these drains greatly exceed that of the main sewer into which their discharges finally empty. Were a ventilating shaft set up on the main-sewer at any point, wherein an upward draft was created by any method, either that of a furnace or a fan, in order to produce an efficient velocity of exhaust within it, so that a downward current should obtain in all the waste pipes of the dwellings communicating with the sewer, would require almost a hurricane within the latter; and even this would prove inoperative at the waste-pipes, were an

accidental opening made in any branch, such as would occur during the progress of any repairs, or by the removal of a man-hole cover. And again, if this requisite velocity of air-current extended to the house-drains and pipes, all the water-traps, as at present arranged, would be in danger of becoming at once unsealed, in which case the interruption to the action of the draft, by any accidental opening being made in the main, might result in the discharge of the gas within the dwelling by its superior levity.

The failure of mechanical expedients to remove the gases after they were formed, led to the adoption of various chemical ingredients for their destruction, or to prevent their accumulation in the sewers. Carbide of iron has been recommended. Lime has been used and recommended, from its purifying effects in the manufacture of illuminating gas. Chlorine-gas has been proposed by placing chloride of lime in trays for the evaporation and combination with sewer-gas. Sulphurous acid has been tried pretty extensively, but is now reported against. Charcoal placed in trays within the man-holes and renewed from time to time, has had quite a run in England, but is no longer recommended, save by the patentees of the contrivances for its use; and the difficulty in the way of a practical supervision, and preservation in working order, of this as well as other chemical appliances, has led to their disuse, save under exceptionable circumstances, and would prove of little practical benefit in our cities. The use of the rain-water leaders from the roofs of houses has been long in use, and from its convenience and cheapness has been recommended as a sufficient means of ventilation; but in heavy rain-storms, when the sewers are gorged, and the increased flow within them is backed into the house-drains, and ventilation is then most needed, it is then that their service as

ventilators fail, and unless at such times some other facility is afforded for the escape of the gases elsewhere, there is danger of their being forced into the dwellings.

The conclusion to which we have arrived is, that while the furnaces, blowers, exhaust-fans, steam-jets, and other mechanical appliances, which, in ignorance of the natural processes going on within the sewers, have been proposed, tried, and abandoned, as also the various chemical preparations to neutralize the poisons of decomposition, or to prevent their dangerous increase, have proved equally unsatisfactory, the sewers will ventilate themselves by the simple expedient of constructing man-hole shafts on the street mains at intervals of not less than every 100 feet, and instead of a solid cover at the level of the street, close the opening of the man-hole by a cast-iron perforated cover or grating, and require the openings therein to be freed from ice and snow in the winter months. If the openings in the covers be made properly, as shown in Fig. 46–7, the refuse of the street traffic will not close them at other seasons. This and the connection of the waste-pipe from the dwelling being made without a trap of any kind, as also the rain-water leader from the roof being untrapped, as shown in Fig. 71, will enable the sewers to *breathe* and ventilate themselves at all times.*

An objection has been brought against this method which has some weight in the narrow streets and crowded tumble-down structures of the older countries; that is, the sewer-gases being discharged by this method into the streets and at the house-tops, this proximity renders them liable to return through the open windows into the houses. Bear-

* It has been incidentally noted elsewhere, that the unobstructed current of discharge from the waste-pipes of the houses becomes an important factor in preserving the sewers free from deposit.

ing in mind what has been said previously, that whatever ignorance may exist as to the nature of the means whereby disease is propagated by the organic vapors of decomposition in sewers, the one fact is indisputable, *that dilution by fresh air deprives it of its noxious properties;* and if the current of sewage within, and toward the outfall of the sewers, be maintained without interruption, as it may and should be, time will not be afforded for dangerous decomposition being set up in the sewers.

Fresh sewage is not pleasant to the smell, but we have yet to learn that it ever did any harm in the open air; and as to the sewer-gas from openings above the roof being likely to poison the air in the upper rooms of dwellings, we can only say that, if the upward currents from the sewers through the soil-pipe or leaders terminated *below* these windows, there might be some ground for the apprehension; but so far from this being the case, the discharge would or might be made to take place many feet *above* their level, and with an upward tendency, and a dilution and diffusion in proportion to the cube of the distance from the point of discharge. And finally, if the sewer-air be not allowed free escape into the street and above the roofs of the houses, but is shut up within the sewers, with a view to its being operated upon by mechanical or other expedients, it will be very likely at times to find its way, under pressure, either through leaky joints in the pipes or imperfect traps, into the bedrooms, with every convenience there for its active dissemination; and further we believe that, in reality, the danger from the gas escaping from the sewers themselves is so small compared with that which is generated in foul house-pipes, traps and drains, that if the cleansing and the ventilation of the latter be properly attended to, by timely flushing, under a judicious system of piping,

well constructed, the danger from the sewers themselves is too remote to excite any undue apprehensions, although the noxious vapors may still be called *sewer*-gas. If the little trouble of attending to this is considered as objectionable, it should be remembered that the system of sewering and house-drainage is a hydraulic *machine*, and like all other machines, requires at times an intelligent supervision.

HOUSE-DRAINAGE.

We come now to the end and purpose of all that has occupied us in the preceding pages. The sewage which was discharged from the dwellings, was to be removed with the least possible delay or inconvenience to the occupants; and as we have shown that, by the adoption of the water-carriage system, there was less apprehension than by any other mode, that, what once left the house could ever return to endanger either life or health, so whatever tends to perfect this system and render its working sure, is an object to be attained. In the water-carriage system of sewers, that they may be efficient at all times, the smallest possible cross-dimensions were to be given them, consistent with the capacity which the sudden demand upon them at intervals, during heavy storms, called for; and in order that these minimum dimensions should prove efficacious, it was shown that the discharge of rain from the roofs, as also from the surface of yards, was counted on by their great velocity to induce or keep up, in the sewers, currents toward their outfall greater than is usually estimated as possible, and at the same time contribute an additional volume to the sewer, not accounted for, if the flow of the latter were supplied from a single source at the head of the system.

To effect this desirable purpose, it is important that the leaders or conductors from the roofs, which contribute in

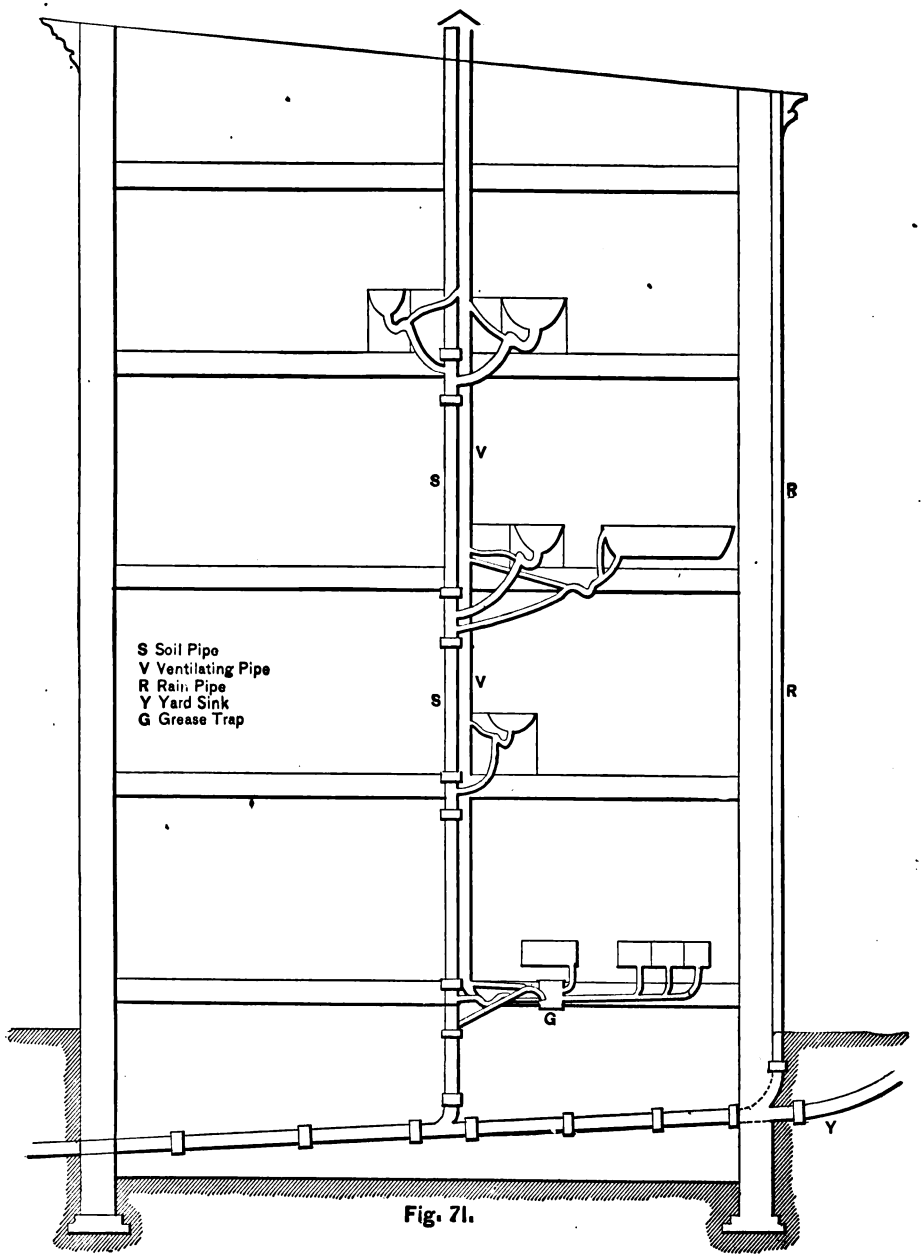

S Soil Pipe
V Ventilating Pipe
R Rain Pipe
Y Yard Sink
G Grease Trap
V
S
R
V
S
R
G
Y

Fig. 71.

storms their waters at a high velocity, as also the main drain from the house, should, if possible, all enter the sewer direct, without any retardation whatever to the velocity of their discharge, by the interposition of valves, siphons, traps, or other artificial obstructions interposed to their free flow. This serves one purpose, and if at any time the sewer wishes to "breathe" into the open air through the soil-pipe, or rain-water leader, or man-hole cover, no impediment should be interposed to its action. This will effect another purpose, and we regard this free communication with the sewer as the first requisite to a proper house-drainage, and fortunately also to a proper ventilation of the house-drains. As previously hinted at under the head of ventilation, to one individual poisoned by gas generated in the sewers of a proper water-carriage system, there will be scores poisoned by the foul air from unventilated house-drains and pipes.

While the office of house-drains is to carry off all liquid refuse, waste water, and fæcal matter, it is not less their duty to prevent the entrance of gas from the sewers into the houses, and also to provide a ready exit to the open air for all gases generated within the pipes themselves. This threefold function can only be realized by a proper attention to certain well-known principles attending the movement of gases, the practical working of which is readily understood; and with these principles in view, there need be no difficulty in providing absolute safeguards against the influx of gases formed either within the sewer or the drains of a house.

It is scarcely necessary to say that in house-drainage good workmanship is the first essential. No cheap plumbers should be employed. Fifty dollars saved in the plumbing of a house may be at the cost of a life. That such has been the result, can be pretty clearly demonstrated from the

records of almost any Board of Health. The work of the plumber is generally out of sight, and therefore out of mind. If cheaply and hastily done, it is certain after brief service to give way at some point hard to find, and most difficult to reach, from which the sewage will run to saturate the partitions, floors and ceilings to an incurable extent, converting into a pest-house the home which otherwise might have been healthy. The proper way to avoid this is to construct at first in the most substantial manner all the plumbing work of the house. Drainage-pipes should never be buried beneath the floor of the cellar, nor should they be built in the walls above the cellar, when it is possible to carry them up through closets or in wooden casings. Cast-iron drain-pipes should always be used within the walls. Between the house and the street sewer, stone-ware pipes may be laid, but these must be well and carefully laid on a well-prepared foundation, and under no consideration should they be allowed to enter the house. Even if well laid in cement, the best stone-ware pipes, full of cement joints as they must be, though buried beneath a cemented floor, are liable to, and frequently do after short use, give off an amount of stench that can be easily perceived and is very offensive in the lower part of the tenement. Lead soil-pipes are equally objectionable, being easily perforated by the careless driving of a nail or by the teeth of vagrant rats, and liable to be broken by their own weight when perpendicularly erected to any great height. Many sanitary engineers give lead pipes preference over iron. This is a great mistake, as practical experience in this country has fully demonstrated. It has been found that the objection urged against the latter—that they are liable to rust out from the inside—is invalid, since they soon become coated with a greasy film which entirely prevents corrosion. The joints

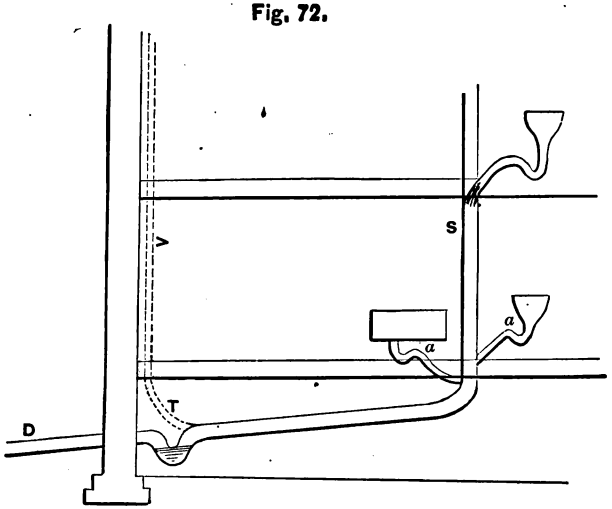
of the iron pipes must be thoroughly caulked with lead, and not, as is frequently done by many of our plumbers, with sand and putty. Such joints should never be made. The same is true of mortar or cement, which are, if anything, worse than no joints at all, as contributing to a mistaken sense of security. While cement is a very proper material for the joints of stone-ware pipe, its action under changes of temperature being different from that of iron, it may crack and crumble, leaving the joint partially open, and to that extent pervious to both gases and liquids. A proper and safe joint between lead and iron pipes, may be made in two ways. The first is by means of a tinned brass ferule. The taper end of the ferule is slipped into the end of the lead pipe and soldered to it. The other end (which when the junction is between a small lead pipe and a larger one of cast-iron, is provided with a flange) is dropped into the iron pipe, and secured in place by a lead caulked joint. Another method equally good if properly done, is by the use of an iron ring. This ring is slipped on the lead pipe, and the latter then turned over it. Thus reinforced, it is slipped into the hub of the iron pipe and caulked as usual with lead. These methods are safe and durable, and will outlast the pipe itself.

The most important part of the whole system of the drainage of a house is to carry the soil-pipe of a uniform size direct from the cellar with an opening above the roof. This is not to be omitted under any circumstances in the construction of a new building, and will generally be found in itself a remedy where difficulty is encountered from the escape of sewer-gases in houses already constructed. The object of this pipe is to afford a means of conveying the vapors from the sewer *through* the house to the open air above, where they are readily dissipated, instead of *into* it

for distribution through the different apartments whenever a defective joint or an inefficient trap may give the opportunity for their escape. Into this soil-pipe will run all waste-pipes from closets, basins, sinks and tubs. No one of these waste-pipes must be allowed to empty into another, but each should have its separate connection with the soil-pipe. Where more convenient, basins or sink wastes may be allowed to discharge into the lower part of the trap of the water-closet, provided proper traps are used at their upper ends with vents from the top of these traps to the open air, but not otherwise.

The question of the proper number and location of traps is one about which there is much difference of opinion. Too many traps are worse than none at all. The placing of a trap at the front wall of a house where the soil-pipe leaves the cellar—a practice recommended by most plumbers in all cases, no matter what the plumbing arrangements above may be—is the cause of absolute danger unless the soil-pipe be ventilated between such trap and the basin, sink, or closet connection nearest to it. The reason is evident. Suppose Fig. 72 to represent in part the drain-pipes of a house, with a trap *T*, which should always be outside, at the point where the waste-pipe leaves the cellar. The pipes are filled with foul gases, emanating from the sewage which flows through them of the same character as the gases of the sewers. When the water is liberated from the closet above, for the first few feet of its descent it forms a nearly solid piston which forces a quick escape of the contents of the pipe below, which will escape at the point where there is the least resistance. This of course will be through the small traps and light water-seal under the wash-basin and kitchen-sink, these being more easily forced than the large body of water in the trap at *T*; and as a

Fig. 72.



consequence the sewer-gases are belched into the sleeping and living apartments every time the water-closet is used. Unless the soil-pipe is continued to the roof—a precaution but seldom taken—a similar effect will be produced by an expansion of the air in the pipes from an increased temperature. Some plumbers attempt to avoid this difficulty by placing vent-pipes at the top of the small traps, at *a* (not shown). This will not always answer, as the vent that can be thus given is too small to admit of an escape sufficiently rapid to perserve the water-seal. A trap *T* at the outlet of the soil-pipe would thus demand a ventilating pipe as *V*, and this of the size of the soil-pipe and extending above the roof. But if, on the contrary, the pressure from the sewer should, from causes liable to occur, be great enough to force the trap *T*, unless the soil-pipe *S* also be extended to the roof, any imperfectly sealed trap, or other defect in the plumbing, will give a ready access to the house of sewer-gas unless the trap *T* were also vented at the lower elbow

as well as the upper. If the house-drain *D*, however, becomes closed by the accumulation of sewage in the street sewers, the extension of the soil-pipe to the roof alone cannot be relied upon to relieve the smaller traps from being forced, and the necessity for venting all traps into a separate ventilating pipe which extends to the roof becomes necessary, as the only measure of absolute safety. It is shown in the case of Fig. 72, that unless by a vent-pipe *V* carried from above the trap *T* to the external air (and the only available termination of such a pipe would be at the roof), there is always danger of some of the smaller traps being forced; in order to avoid this, and to meet the case just cited of the house-drain being sealed at the street sewer, a ventilation entirely independent of that afforded by the soil-pipe becomes necessary, and will be attended by less expense than would the double pipe *V*. This proposed arrangement is shown in Fig. 71, wherein every trap has a vent-pipe connecting with an independent ventilating tube *V*, of the same size as the soil-pipe *S*, extending from the lowest trap to the roof. By adopting the method shown in Fig. 71, and ordinary care being exercised by the plumber in the selection of materials, and good workmanship, complete immunity from the inroads of sewer-gas may be had.

It has been objected to this method of allowing a free passage for the sewer-air through the main soil-pipe of a house, that dispensing with a water-trap at the lower part of the house-drain permits of the leakage of sewer-gas at such points as may be defective, which the higher temperature of the house facilitates. This is true; but the same imperfect supervision which would permit such inferior materials and workmanship in house-plumbing, could not be guarded against by the introduction of a water-trap as

an absolute means of safety against neglect; for it is well known that no such trap can be relied upon as efficient under all circumstances; and if the pipes leaked, however perfect the trap, gas would enter the house. Every year or so, the plumbing of a house should be carefully inspected, and such inspection, instead of being considered as rendered necessary by possible defects in the plumbing, should be regarded as the only means for establishing an intelligent confidence in the safety of our surroundings; and the custom once established of such inspection, would do much towards diminishing the amount of *cheap* work. The student is referred for valuable hints on this subject to "Defects of House Drainage and their Remedies," by Edward S. Philbrick, Civil Engineer, Boston.

The acknowledged imperfections existing in the ordinary house-drains, and the readiness with which individuals are induced to try new expedients to secure immunity from the effects of sewer-gas, *providing they are attended with no increased expense*, has tended to bring forward a good many schemes for improvement in house-plumbing, which further experience has laid aside as of little value. There is one, however, the fallacy of which we feel called upon to notice, as its use we think may be attended with danger, and the arguments in support of it are so plausibly given, as to be calculated to mislead, though we are well assured that the proposer of the scheme has no personal interest in its general adoption. It will be found in Appleton's New York Medical Journal for April 1879, under "Sewer-Gas in Houses," illustrated (one of which illustrations we give in Fig. 73), as having been successfully adopted by its designer and others who have been led to adopt it.

The method consists in establishing an upward current through the soil-pipe by a ventilating cowl above the roof,

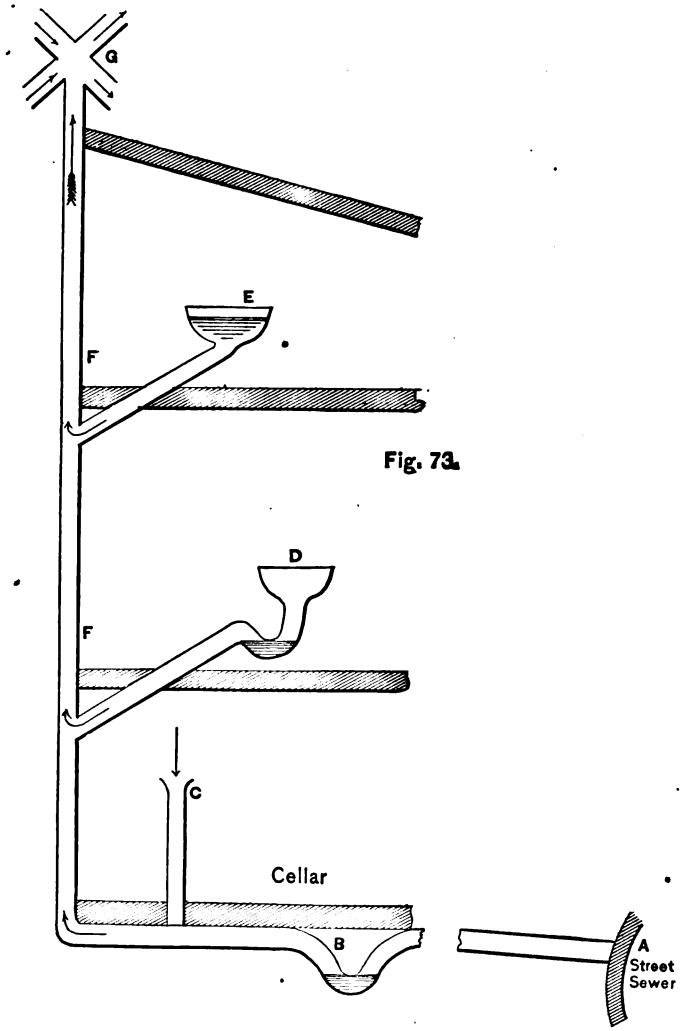


Fig. 73.

and dispensing with all independent ventilation of the traps requires the draft *from* the rooms wherein any waste-pipes or closets are placed, through the waste and soil pipes into the open air above the roof; the supply to this draft being obtained from an open stand-pipe in the cellar, as shown in Fig. 73, claiming, as will be seen, that by this method, all

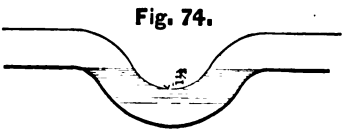
danger from the air in the house-pipes entering the rooms is completely obviated, and the direction of the current reversed to one from the rooms into the soil-pipe in all cases. If this were so, and a strong upward draft through the soil-pipe insured at all times, the problem would be solved, and nothing further need be sought in this direction. But no ventilating cowl yet devised will insure such action. Nothing less than an exhaust fan driven by some power less variable than that derived from atmospheric currents, and thus wholly unsuited to private houses, would insure such a draft. We do not question that, under certain favorable circumstances, this system may in part have worked well, but practically it will be found to be unreliable. To illustrate its uncertainty by a single example:

Whenever the street sewer, after running with a small flow of sewage, is suddenly gorged to nearly overflowing, as would result from a heavy rain-storm, a current of air is driven into the house-pipes by the pressure in the sewers at the same time when, from atmospheric conditions, a current may have been established from the external air down the soil-pipe—a by no means unlikely contingency. These combined pressures, if they do not force the small traps of the closets, will force the air from the soil-pipes into the house at the time the closets are being used. And again, when the street-sewer, after such gorging, rapidly discharges its contents, a reverse downward current is induced in the house-drain and soil-pipes, when, if the traps are without independent ventilation, they will become unsealed, and thus open to the foul emanations from the house-pipes until such time as the upward force of the ventilating cowl shall have obtained the mastery of the draft. It will be observed that this system holds to the belief, which we have elsewhere expressed, that the foul-

ness adhering to the house-pipes is, in general, a more fruitful source of mischief than is the sewage running in the street-sewers. Nothing will meet the difficulty of preserving the house free from these gases, whether from the sewer or the drain-pipes, so satisfactorily as the method previously pointed out in Fig. 71.

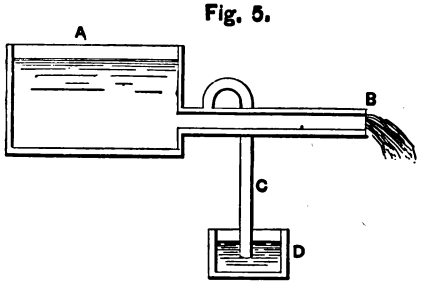
Traps must always be placed under and as close as possible to every sink, basin, tub and ordinary water-closet. For the water-closet, traps should be used having an inch and a half seal—that is, the water in the traps should rise an inch and a half above the lowest bend in the upper side. Running traps, such as Fig. 74, for basins, sinks and tubs are unsafe, and should never be used without a vent-pipe from their highest point to the open air or ventilating pipe. Without this they are liable to be siphoned out when used unless extraordinary care be observed. They are also liable to be unsealed by any disturbance in the soil-pipes toward which they empty.* The insecurity of these traps may be easily

Fig. 74.



* If house-drains run full, they are liable to drain the traps above them, unless especially ventilated, from the effect of what is called "induced currents." The following experiment will illustrate it, from Ewbanks' Hydraulics. Let a reservoir *A* discharge its water by a pipe *B*, the level of the water being 32 inches above the outlet of *B*, the diameter of the latter pipe being 1½ inches and its length 5 inches; a tube *C* being connected with it two-thirds of an inch from the reservoir and descending into a vessel of water *D*, the level of the water in the latter being 22 inches below that in the tube *B*. When the water from *A* flowed through *B*, its effect after exhausting the air in the curved bend, was to empty the water-pan *D* by means of a current induced in *C* by the action of the running water through *B*.

Fig. 5.



shown. Take an ordinary inch or larger lead pipe, bend it in the shape of a running trap, and enlarge the upper end to represent a small bowl. Fill the trap with water, as represented at *W*, Fig. 75. Pour in a tumblerful of water quickly at the top, and when it has run off at the bottom, it will be found to have carried with it about one-half the water from the trap, which will thus be left unsealed. This trap may be made safe by affixing a ventilating pipe from the upper part of the bend at *V* to the external air or ventilating tube. A trap that cannot be siphoned may be had

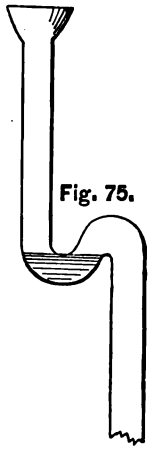


Fig. 75.

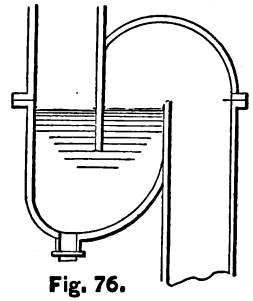


Fig. 76.

for about the same cost as the running trap, which it should entirely supersede for all purposes of house-drainage when water only is to be disposed of. (See Fig. 76.) In this the column of water is broken, and it is not possible to unseal it, but it is somewhat open to the objection of retaining fæcal matter, and therefore is used preferably on water wastes. All water-traps are more or less unreliable from the fact that, under very slight pressure, they permit of the absorption of gas below, and long before arriving at the point of saturation give off the gas from the surface above.

Safes (which are shallow metal pans to collect any leakage), under basins or closets, if the plumbing is well constructed, are useless and had better be omitted. If the work has been done in such a defective manner as to require the protection of a safe, accompanying the job will probably be found a drain-pipe from the safe connecting directly with the soil-pipe below the basin trap, forming a convenient channel to conduct the sewer-gases around the water-seal to the bed-chambers. Traps, if constructed in these small safe-drains, are of no use; they will be siphoned out or their contents will evaporate as often as they are filled. If these safes are insisted upon, they should be drained to the kitchen sink, thus avoiding all possibility of being made a conduit for noxious odors, and at the same time emptying where their discharge would quickest give warning of a defect in the water-pipes above.

Most writers condemn the practice of putting wash-basins in sleeping apartments, or even in dressing-rooms joining the bed-chamber, it being claimed that the chances of imperfect work are too great, even in the best-constructed dwellings, to admit of their being so placed with safety. We entirely disagree with these authorities. There is no difficulty in so sealing and ventilating drains, basins, and even closets, by the adoption of the independent ventilating pipe shown in Fig. 71, that there will be not the slightest danger of any noxious gases escaping from them. With ordinary care in arrangement and workmanship, and the exercise of a moderately intelligent supervision, all possibility of danger may be avoided, and the necessity for depriving ourselves of any of the "modern conveniences" connected with house-building entirely obviated.

Ordinarily an entire dwelling above the basement is protected from the gases from the sewers only by a trap under

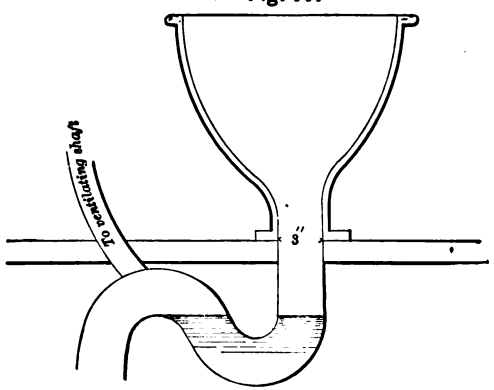
the water-closet and a trap in the soil-pipe near its outlet into the house-drain. Should the water-seal in either of these traps become broken by any means (and it is liable to from numerous causes) the current from the sewers will be direct into the sleeping rooms, or wherever there may be a bowl, basin or sink. The passage of sewer-gas as it bubbles through this trap from the pressure in the sewers may be frequently heard in all houses drained in this manner, and of the insufficiency of the outlet-trap we have already referred.

In the drainage of a house properly constructed, as represented in Fig. 71, the pipes running to the top of the house afford ready escape for all sewer-gases, entirely relieving from pressure all the traps and the various parts of the drainage throughout the building, and furnishes air behind sudden discharges of water from the closets for the prevention of siphonage. Each basin, closet, tub and sink has its trap close to the opening, with an independent waste-pipe to the main soil-pipe. Thus the flow from no one waste-pipe can interfere with the trap of another.

A matter of the greatest importance is the selection of a proper water-closet. It has become the fashion among all sanitary writers to condemn as utterly unfit for use the "Bartholomew" or ordinary pan-closet at present so generally in vogue. It is certainly not the best form of closet either for cleanliness or convenience; but it was far in advance of anything preceding it, and is still a very good apparatus if kept in proper repair and condition. It is preferable for in-door use to the hopper closet, notwithstanding the statements of many theoretical writers to the contrary. Thousands, probably hundreds of thousands of houses are supplied with closets of this pattern, which have been in use for many years, requiring meantime but slight

repairs, and entirely fulfilling the purpose for which they were intended. Nevertheless, now that closets of a superior pattern can be obtained, the "Bartholomew" is not recommended for use in first-class dwellings; and even in houses

Fig. 77.



Hopper Closet

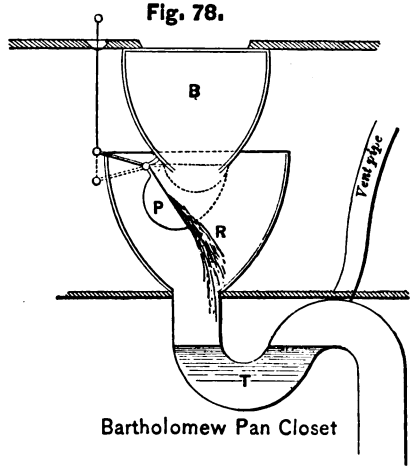
where it has been long in use, the substitution of a modern closet in its stead will be found of the greatest benefit. For tenement-house use, hopper closets in an *out-door building* are recommended, from their simplicity. Care must be taken in their arrangement, however, to place their supply-pipes below the reach of the frost.

For in-door use, this closet can be made comparatively inodorous by ventilating the bowl, just below the seat (which should be provided with a close cover), through a flue to the chimney, and providing appliances for flushing it freely and rapidly. All this, however, may make the cost about equal to that of the more approved closet of modern construction, and entirely overcome the only argument in its favor, namely, that of cheapness.

The objection to the pan closet or Bartholomew hereto-

fore spoken of, may be seen by a glance at the Fig. 78. It is simply that the large iron receiver *R* below the bowl, after short use getting fouled, becomes the source as well as the receptacle of offensive gases, which, every time the pan is lowered and the water therein allowed to descend, are forced into the room above. This foulness, by the adhesion of fæcal matter, becomes so great by long neglect at times, as to prevent the proper opening of the pan *P*, and recourse is had to what the plumbers call "burning out" for its removal. It may be said, however, that this objection exists to a greater or less extent in all closets that require a trap below the upper water-seal. This is undoubtedly so; and hence the preference given to a closet that is perfectly sealed without a trap, from which every particle of foul air or sewer-gas is immediately drawn downward by the descending water whenever the closet is used. This receiver *R* in the pan-closet is beyond reach—indeed, its presence is unknown to the majority of housekeepers—and therefore it escapes the frequent cleansing which it should receive. In addition to this objection, the gearing by which the valve is worked is complicated and easily disarranged, while the necessary apertures for its working afford means for the escape of noxious gases from the interior of the closet.

Fig. 78.



B, Crockery Bowl. *R*, Iron Receiver. *P*, Pan when open. The dotted lines show the Pan when in position, full of water. *T*, Trap filled with water.

Notwithstanding these apparently vital defects in this

form of closet, we have for twenty years past resided in a house provided with none other, and while some form of zymotic disease presumably derived from sewer-gas has appeared in the neighborhood, our premises have not been invaded. An evidence, so far as it goes, in support of the opinion given under the head of Ventilation, that the danger to be apprehended from poisoning from sewer-gas, derived from the sewer itself, is not very much to be apprehended, and that the foulness gathered in the house-drains will not be likely to *generate* the disease germs, whatever they may be, but will furnish the pabulum upon which, if they are living organisms, they feed and flourish. In other words, an inferior pattern of water-closet may be sufficiently safe against the danger of importing disease from without, or favoring its generation within; but disease once within your house, such form of closet might prove a powerful machine for its extension among the inmates.

The "Jennings closet" has heretofore been considered as the best form of closet in use, but a late report from the Board of Health of Brooklyn condemns it as possessing but few advantages over those of the pan-closet, and considers that it has several faults from which the pan-closet is free, and recommends the Pearson's Twin Basin closet as preferable in every way to the Jennings or any closet now in use. So rapid do improvements appear in everything connected with sanitary appliances, that we believe the objections to the "Jennings closet" have been removed since the date of that report, and the "Jennings New Trapless Closet," so far as we can judge from its theoretical principles, leaves little to be desired in point of offering proper security from sewer-gas, and in our opinion is no way inferior to the twin closet of Pearson. Both are trapped within themselves, and are operated by a plunger with India-rubber disc,

and the machinery, to appearance, less likely to get out of order than that of the pan-closet, and neither of them offer any opportunity for excrement to lodge above the water-seal. Both of these closets are of English manufacture, but neither of them preferable to a late Boston-made closet by J. Zane & Co., which is also trapped within itself, and the overflow regulated by a simple ball-cock and operated by solid plunger. So far as witnessing the operations of all these closets and examining their principles of construction would enable one to judge of their merits, we think that the preference is due to the Zane closet; but in this matter, nothing short of a continued use of these utensils by an intelligent individual who understands the purpose and aim of the various contrivances used, and their bearing upon the end in view, viz., absolute immunity from gases generated in the sewer or the house-pipes being allowed access to the rooms of the house, can justify a decision that in all points of excellence either one of these three is decidedly superior to all others.

The soil-pipe in all plumbing-work should be of iron with caulked lead joints, and no T-branch* should be allowed in any place, but always a Y-branch, and it is better to continue this cast-iron pipe to the street-sewer rather than use any "crockery pipes" about the house-plumbing.

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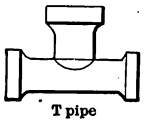
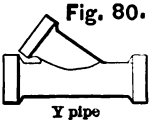
* Quantities of T-pipe, Fig. 79, are to be seen among plumbers' supplies, indicating a large use of this description of junction, particularly of stone-ware pipe, but their use under any circumstances likely to arise, whether within the house or on a line of sewers, is to be condemned, as tending to the formation of deposits through the eddies produced by the meeting of right-angled currents. There is always one direction, and but one, which will insure a proper scouring action by the current of the liquid, and the junction should always be made in this direction by a Y-pipe, as in Fig. 80.

Fig. 79.



T pipe

Fig. 80.



Y pipe

This pipe should not be less than 4″ diameter. It is needless to state inclinations at which pipes are said to keep themselves clean; no fall without a sufficiency of water will do this; *all the fall which can be had*, with a uniform rate of inclination, without sags or bends, should be given to the soil-pipe, and if this fall is too slight, it must be assisted by repeated flushings.

In reference to the above, we quote from Mr. Philbrick as follows: "A frequent mistake is made in laying the large sized pipes for drains, arising from the notion that small pipes are more likely to be choked. The fact is, that all increase of size above the requirements of capacity is an actual injury, by diminishing the scouring power of the current; so that, if laid with a fall of two or more in a hundred feet of length, a four-inch pipe is better than a larger one for a house-drain used by some fifty persons, because with this limited flow the small one would scour better than the larger one. If rain-water is admitted from the roof, either for convenience or flushing, a larger size is perhaps needed, but six inches is ample even then for an ordinary house-roof. If the fall is less than two per hundred, flushing may be needed. As such drains seldom run half-full, they cannot be relied upon as self-cleansing, unless laid with the rate of slope of say two per hundred for four-inch drains, or one and a half per hundred for six-inch drains. For hotels and large establishments containing many receptacles for sewage and many branch-drains, a six-inch pipe would be ample unless rain-water be admitted from extensive roof-surfaces. In this case the size of the drain is governed, first, by its rate of fall, which is generally limited by local topography; and second, by the size of the roof to be drained. . . . . Ignoring the volume of sewage as comparatively insignificant, the problem then

becomes a question of hydraulics, and reference must be had to the governing elements and well-known physical laws thence computing the required size."

A grease-trap should interpose between the kitchen sink and the house-drain to arrest the grease which, condensing in the soil-pipe or house-drain, will readily close it. This is a fruitful source of trouble, particularly in pipes with slight falls. It is remedied by the use of a grease-trap, which should be placed below the kitchen sink and consists of a covered stone-ware basin, circular in plan, about 16″ in diameter and 16″ high, with inlet-pipe near the top, and the outlet-pipe turned down to within six inches of the bottom, forming a water-trap, above which the grease floats and the waste water drains off from below. The only objection to this is the suspicion of sewer-gas returning into the house by the inlet-pipe; but if ordinary care is taken to insure the basin being half full of water, which directly under the kitchen sink cannot be very troublesome to effect, will prevent any difficulty from sewer-gas. No other waste than from the sink should be allowed to enter the grease-trap.

For the drainage of gardens and yards, a catch-basin or sink is used, which is a small water-tight basin, and may be built of brick, but is better of stone-ware, and covered by a stone curb with a circular opening, into which fits a strainer or grating of stone-ware or metal, which may be removed for cleaning out the deposit which collects from the yard. If the sink be of stone-ware, the siphon-trap forms a part of it as shown in Fig. 81, otherwise a siphon-trap is built into the brickwork and connected with the house-drain by a branch which unites with the roof-leader. As to whether the main drain passes under the foundation wall, or through it, is a matter of no moment; in either case the

necessity for preventing any settlement injuring the pipe, as also of properly securing it against derangement of any kind, is obvious, and the means for effecting it, equally so.

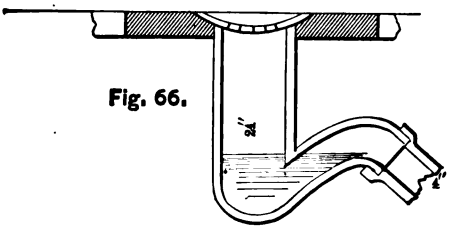


Fig. 66.

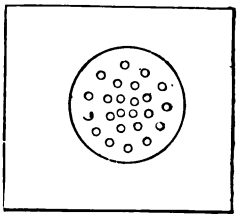


Fig. 67.

It is desirable that it should not be buried below the cellar floor, but be carried against some of the side walls of the house, to which it is not unfrequently attached by iron hooks. If the pipe be of lead, which by the way is every way inferior to a properly-caulked iron pipe, this method of attachment is very insecure, and in any event it should be laid upon a properly-supported shelf to insure uniform support, and be carried up through the various stories of the house in a casing to which ready access may be had.

The house-drains will connect with brick sewers at about the level of the *ordinary* flow of the sewage, and with pipe sewers at about half their height above the invert or bottom.

We have confined ourselves to exhibiting principles of house-drainage and plumbing rather than the practice; the latter is very varied with probably equal chances of a good result, and the reader is referred for copious details to a late work on "House Drainage and Water Service," by James C. Bayles of New York.

APPENDIX.

A.

MAIN-DRAINAGE OF LONDON, FROM A PAPER TO THE INSTITUTION OF CIVIL ENGINEERS, BY THE CONSTRUCTING ENGINEER SIR JOSEPH BAZELGETTE.

THE object sought to be attained in the execution of the drainage-work, was the interception of the sewage (as far as practicable by gravitation), together with so much of the rainfall mixed with it as could be reasonably dealt with, so as to divert it from the river near London; the substitution of a constant, instead of an intermittent flow in the sewers; the abolition of stagnant and tide-locked sewers, with their consequent accumulations of deposit; and the provision of deep and improved outfalls for the extension of sewerage into districts previously, for want of such outfalls, imperfectly drained.

According to the system which it was sought to improve, the London Main Sewers fell into the valley of the Thames, and most of them, passing under the low grounds on the margin of the river before they reached it, discharged their contents into that river at or about the level, and at the time of low water only. As the tide rose it closed the outlets, and ponded back the sewage flowing from the high grounds; this accumulated in the low-lying portions of the sewers, where it remained stagnant in many cases for eighteen out of every twenty-four hours.* During that period the heavier ingredients were deposited, and from day to day

* The range of tide at London is at times as much as 22 feet.

accumulated in the sewers; besides which, in times of heavy and long-continued rains, and more particularly when these occurred at the time of high water in the river, the closed sewers were unable to store the increased volume of sewage, which then rose through the house-drains and flooded the basements of the houses.

The effect upon the Thames of thus discharging the sewage into it at the time of low water, was most injurious, because not only was it carried by the rising tide up the river, to be brought back to London by the following ebb-tide, there to mix with each day's fresh supply,—the progress of many days' accumulation towards the sea being almost imperceptible,—but the volume of the pure water in the river, being at that time at its minimum, rendered it quite incapable of diluting and disinfecting such vast masses of sewage.

In the system now adopted, it has been sought to remove these evils by the construction of new lines of sewers, laid at right angles to the existing sewers, and a little below their levels, so as to intercept their contents, and convey them to an outfall 14 miles below London Bridge. As large a proportion of the sewage as practicable is by this means carried away by gravitation, and for the remainder a constant discharge is effected by pumping. At the outlets, the sewage is delivered into reservoirs situate on the banks of the Thames, and placed at such a level as will enable them to discharge into the river at or about the time of high water. By this arrangement, the sewage is not only at once diluted by the large volume of water in the Thames at high water, but is also carried by the ebb tide to a point in the river 26 miles below London Bridge, and its return by the following flood-tide, within the metropolitan area, is effectually prevented.

At the threshold of any inquiry into this subject, the following important points required to be solved:

1st. At what point and state of the tide can the sewage be discharged into the river so as not to return within the more densely inhabited portions of the metropolis?

2d. What is the minimum fall which should be given to the intercepting sewers?

3d. What is the quantity of sewage to be intercepted, and does it pass off in a uniform flow at all hours of the day and night, or in what manner?

4th. Is the rainfall to be mixed with the sewage, in what manner and quantities does it flow into the sewers, and is it also to be carried off in the intercepting sewers, or how is it to be provided for?

5th. Having regard to all these points, how are the sizes of the intercepting and main-drainage sewers to be determined?

6th. What descriptions of pumping-engines and of pumps are best suited for lifting the sewage of London at the pumping stations?

The position of the outfalls and the time of discharge into the river were arrived at in the mode described in the following extract from the Report of the late Mr. Robert Stephenson and Sir William Cubitt, wherein they give a brief summary of a series of experiments made upon this subject:

"On the 13th of July, 1851, a float was put into the centre of the river opposite Barking Creek two hours after high water. This time was chosen, because it was found that sewage discharged into the river two hours before high water arrived at about the same point above Barking Creek as sewage discharged two hours after high water did by the next flood tide. At low water the float reached 11¾ miles below that point, and returned with the next flood tide to 1 mile above it, having gone 12¾ miles that flood, it being then the period of spring tides.

"As the neaps came on, the float continued to work lower down at each succeeding high water, and by the 24th of July it was 13 miles below Barking Creek at high water, having gone down the river 1¼ miles during the falling

off of spring tides to neap tides. As the floods again became stronger, it worked up the river each succeeding tide until the 29th July, when it again came within 5 miles below Barking Creek at high water, having worked up the river 9 miles from high water neap tides to high water spring tides, the excess of the ebbs over the floods being only 5 miles in fourteen days."

"Another experiment was tried at the same place on the 6th of August, 1851, it being then lowest neaps, and the float being put down two hours after high water. It worked up each succeeding high water till top springs on the 12th of August, when it reached 6¼ miles above Barking Creek at high water. The float then again worked down the river, till the 20th of August, 9¼ miles below Barking Creek, being a distance of 16 miles during the falling off of spring tides to neap tides. The excess of ebbs over the floods would in this case have been about 7 miles in fourteen days. The wind and other causes would vary the result, but it may be roughly assumed, that a substance in suspension works up the river about 1 mile a day at each high water as the springs strengthen, and down the river 2 miles a day as they fall off."

The main object was, of course, to determine how near to London the sewage could be discharged into the river, at or near high water, without finding its way back again to the inhabited parts of the town. The experiments proved that it was essential to go as far as Barking Creek; and also, as regards the level of the discharge, they demonstrated that it should take place at or as near high water as practicable.

Now, although it is desirable to fix the place of discharge as far below the metropolis as possible, it will be found that a practical limit to this point is imposed on the north side of the river, by the advantages gained from a discharge by gravitation, and by the necessity of maintaining a sufficient fall in the sewers; and on the south side, in order to preserve as a safety outlet a discharge into the river at low water by gravitation, in case of accident to the pumps, as well as during excessive floods.

As regards the time of discharge, it is demonstrated by the same series of experiments that—

"The delivery of the sewage at high water into the river at any point is equivalent to its discharge at low water at a point 12 miles lower down the

river; therefore the construction of 12 miles of sewer is saved by discharging the sewage at high instead of low water."

As to the velocity of flow and the minimum fall, though it is necessary to economize the fall of the sewers in order to save pumping, yet a sufficient velocity of flow to prevent deposit must at the same time be maintained, and the question—What is a sufficient flow? must be determined.

Upon this point Mr. Wicksteed, in his Report upon the Drainage of Leicester, states:

"From experiments made by me with great care, I find that with a bottom velocity of 16 inches per second only (or 0.90 mile per hour) heavy pieces of brick, stone, etc., will be removed, and that with a velocity of 21¾ inches (or 1.24 mile per hour), even iron borings and heavy slag will be removed. The above minimum velocity will therefore be sufficient."

Mr. Beardmore, in his work on Hydraulics, states (p. 8) that "a velocity of 150 feet per minute (or 1¾ mile per hour) will generally prevent deposits in pipes and sewers."

Mr. John Phillips states (see First Report of Sanitary Commission, 1847, p. 177):

"From observation and experiment, I find that it requires a constant velocity of current to be running through the sewers equal to about 2½ feet per second, or about 1¾ mile per hour, to prevent the soil from depositing within them."

Professor Robison, in his "Theory of Rivers," states, at page 465, that—

"We learn from observation, that a velocity of 3 inches per second at the bottom will just begin to work up fine clay fit for pottery, and however firm and compact it may be, it will tear up."

"A velocity of 6 inches will lift fine sand, 8 inches will lift sand as coarse as linseed, 12 inches will sweep along fine gravel, 24 inches will roll along rounded pebbles an inch diameter, and it requires 3 feet per second at the bottom to sweep along shivery angular stones of the size of an egg."

It is difficult to lay down any general rule upon this point, because the conditions of sewers, as to the quantity of deposit passing into them, and the ordinary volume of the sewage flowing through them, vary considerably. But

the author does not hesitate to rely upon these opinions, confirmed as they are by his own observations and experience, which lead him to regard a mean velocity of $1\frac{1}{2}$ mile per hour, in a properly protected main sewer, when running half full, as sufficient, more especially when the contents have previously passed through a pumping station.

Having thus determined the minimum velocity, it becomes necessary to ascertain the quantity of sewage to be carried off, before the fall requisite to produce that velocity can be estimated. This quantity varies but little from the water supply with which a given population is provided; for that portion which is absorbed and evaporated is compensated for by the dry weather underground leakage into the sewers. The water supply to various parts of London in 1856 varied from 20 gallons to 25 gallons per head per diem; but a more liberal supply was contemplated, and that supply was likely to be further augmented by an increase in the population in certain districts not then wholly built upon. It was ascertained that a district of average density of population, when wholly built upon, contained 30,000 people to the square mile, so that in districts containing that or more than that number of people to the square mile, the actual numbers were ascertained and provided for; but in districts where the population was below that number, provision has been made for an increase of population up to 30,000 people to the square mile, except over the outlying districts, where provision has been made for a population of only 20,000 to the square mile.

An improved water-supply, equal to 5 cubic feet, or $31\frac{1}{4}$ gallons, per head for such contemplated increased population has, moreover, been anticipated.

Experience has shown that sewage is not discharged into the sewers at a uniform rate throughout the twenty-

four hours, nor even throughout the day. The habits of the population in various parts of London are indicated by the flow of sewage through the sewers; the maximum flow in the more fashionable districts of the West end being two or three hours later than from the East end. Taking, as before, a liberal margin beyond the results of actual measurements, provision has been made for one-half the sewage to flow off within six hours of the day; and thus the maximum quantity of sewage likely hereafter to enter the sewers at various parts of the metropolis, has been arrived at.

How to dispose of the rainfall is a question of considerable difficulty, and has given rise to much diversity of opinion. This arises from the fact that, while it is in itself harmless, and even advantageous, to the river, it sometimes falls suddenly in large quantities. These considerations have induced theorists to advocate that the rainfall should not be allowed to flow off with the sewage, but should be dealt with by a separate system of sewers. This theory is, however, most impracticable. It would involve a double set of drains to every house, and the construction and maintenance of a second series of sewers to every street. Applied to London, it would involve the re-draining of every house and every street in the metropolis; and, according to a moderate estimate, it would lead to an expenditure of from ten to twelve millions of money, while the interference with private property would alone render such a proposition intolerable.

Careful observations of the quantity of rain falling on the metropolis within short periods have been made by the author for many years. Taking an average of several years, it has been ascertained that there are about one hundred and fifty-five days per annum upon which rain falls; of these there are only about twenty-five upon which the

quantity amounts to one-quarter of an inch in depth in twenty-four hours, or the $\frac{1}{100}$th part of an inch per hour if spread over an entire day. Of such rainfalls a large proportion is evaporated or absorbed, and either does not pass through the sewers, or does not reach them until long after the rain has ceased. In the report of Mr. Bidder, Mr. Hawksley, and the author, in 1858, on this subject, it is stated that continuous observations, and as far as practicable protected from disturbing influences, had been taken at the close of the previous year, and that these observations, which were recorded in the Appendix to the above Report, had enabled them to arrive at some reliable conclusions, and that—

"The result of these observations distinctly establishes the fact, that the quantity of rain which flowed off by the sewers was, in all cases, much less than the quantity which fell on the ground; and although the variations of atmospheric phenomena are far too great to allow any philosophical proportions to be established between the rainfall and the sewer flow, yet we feel warranted in concluding, as a rule of averages, that one-quarter of an inch of rainfall will not contribute more than one-eighth of an inch to the sewers, nor a fall of four-tenths of an inch more than one-quarter of an inch. Indeed, we have recently observed rainfalls of very sensible amounts failing to contribute any distinguishable quantity to the sewers."

But there are, in almost every year, exceptional cases of heavy and violent rain-storms, and these have measured 1 inch and sometimes even 2 inches in an hour. A quantity equal to the $\frac{1}{100}$th part of an inch of rain in an hour, or $\frac{1}{4}$ of an inch in twenty-four hours, running into the sewers, would occupy as much space at the maximum prospective flow of sewage provided for; so that, if that quantity of rain were included in the intercepting sewers, they would, during the six hours of maximum flow, be filled with an equal volume of sewage, and during the remaining eighteen hours additional space would be reserved for a larger quantity of rain. Taking this circumstance into consideration, and allowing for the abstraction due to evapora-

tion and absorption, it is probable that if the sewers were made capable of carrying off a volume equal to a rainfall of one-quarter of an inch per day, during the six hours of the maximum flow, there would not be more than twelve days in a year on which the sewers would be overcharged, and then only for short periods during such days. But exceptional rain-storms must be provided for, however rare their occurrence, or they would deluge the property on which they fell. As it would not have been wise or practicable to have increased the sizes of the intercepting sewers much beyond their present dimensions, in order to carry off rare and excessive thunderstorms overflow weirs, to act as safety-valves in times of storm, have been constructed at the junctions of the intercepting sewers with the main valley lines; on such occasions the surplus waters will be largely diluted, and, after the intercepting sewers are filled, will flow over the weirs and through their original channels into the Thames.

Having thus determined the quantities of sewage and rainfall to be carried off, and the rate of declivity of the sewer required for the necessary velocity of flow, the sizes of the intercepting sewers were readily determined by the formulæ of Prony, Eytelwein and Du Buat; and the sizes of the drainage sewers by the useful formula of Mr. Hawksley, which, with some modifications, may be applied to a variety of conditions and circumstances.

With respect to the description of pumping-engines and pumps to be employed, various opinions existed as to the comparative advantages of Cornish or rotative engines, and as to the respective merits of centrifugal and screw-pumps, chain-pumps, lifting bucket-wheels, flash-wheels, and of every variety of suction or plunger pump and pump-valve for raising the metropolitan sewage. In 1859, numerous

competing designs, involving all these principles, were reported upon by Messrs. Stephenson, Field, Penn, Hawksley, Bidder, and the author; and the pumping-engines and pumps subsequently designed for and adopted by the Metropolitan Board of Works, are based upon the recommendations contained in that report. The engines are condensing double-acting rotative beam-engines, and the pumps are plunger or ram pumps, the sewage being discharged from the pumps through a series of hanging valves.

A primary object sought to be attained in this scheme was the removal of as much of the sewage as practicable by gravitation, so as to reduce the amount of pumping to a minimum. To effect this, three lines of sewers have been constructed on each side of the river, termed respectively the High Level, the Middle Level, and the Low Level. The High and the Middle Level Sewers discharge by gravitation, and the Low Level Sewers discharge only by the aid of pumping. The three lines of sewers north of the Thames converge and unite at Abbey Mills, east of London, where the contents of the Low Level will be pumped into the Upper Level Sewer, and their aggregate stream will flow through the Northern Outfall Sewer, which is carried on a concrete embankment across the marshes to Barking Creek, and there discharges into the river by gravitation.

On the South side, the three intercepting lines unite at Deptford Creek, and the contents of the Low Level Sewer are there pumped to the Upper Level, and the united streams of all three flow in one channel through Woolwich to Crossness Point in Erith Marshes. Here the full volume of sewage can flow into the Thames at low water, but will ordinarily be raised by pumping into the reservoir.

With respect to the form of the sewers, as the intercepting sewers carry off only the $\frac{1}{100}$th part of an inch of rain

in an hour, and the volume of sewage passing through them is at all times considerable, the flow through these sewers is more uniform than in drainage sewers constructed to carry off heavy rain-storms. The form, therefore, generally adopted for the intercepting sewers is circular, as combining the greatest strength and capacity with the smallest amount of brickwork and the least cost. In the minor branches for district drainage, the egg shape with the narrow part downwards is preferable, because the dry weather flow of the sewage being small, the greatest hydraulic mean depth and consequently the greatest velocity of flow and scouring power is obtained by that section in the bottom at the period when it is most required, and the broader section at the upper part affords room for the passage of the storm-waters, as also for the workmen engaged in repairing and cleansing.

THE NORTH SIDE OF THE THAMES.

The High Level Sewer commences by a junction with the Fleet Sewer, at the foot of Hampstead Hill, and passes along Gordon House-lane, and across the Highgate-road. It is carried through Tufnell-park-road, Holloway-road, under the Great Northern Railway, and the New River to High-street, Stoke Newington, at Abney Park Cemetery. It then passes under the Rectory and Amhurst roads to Church-street, Hackney; under the North London Railway, through Victoria-park, and under Sir George Duckett's Canal to a junction with the Middle Level Sewer. (See Map.) Up to this point it is a drainage sewer, that is to say, it is a substitute for the open Fleet and Hackney Brook main sewers, which have since been filled in and abandoned; and it has been constructed of such dimensions, as to be capable of carrying off the largest and most sudden falls of rain. It

is about 7 miles long, drains an area of about 10 square miles, and intercepts the sewage of Hampstead, part of Kentish Town, Highgate, Hackney, Clapton, Stoke Newington, and Holloway. A portion of the district adjoining the Hackney Marshes is so low, that it was necessary to drain it through a branch passing into the Low Level Sewer. The form of the High Level Sewer is mostly circular, and it varies in size from 4 feet in diameter to 9 feet 6 inches by 12 feet; its fall is rapid, ranging at the upper end from 1 in 71 to 1 in 376, and from 4 feet to 5 feet per mile at the lower end.

It is constructed of stock brickwork, varying in thickness from 9 inches to 2 feet 3 inches, and the invert is lined with Staffordshire blue bricks, in order to withstand the scour arising from the rapid fall. One tunnel, from Maiden-lane towards Hampstead, is about half a mile long, and great care was necessary in tunnelling under the New River, its channel being on an embankment where it intersects the line of sewer; also under the Great Northern Railway, at a place where its embankment is 30 feet high, the sewer being 7 feet 6 inches in diameter, and the brickwork 14 inches in thickness.

Much house-property was successfully tunneled under at Hackney. One house, adjoining the railway station, was underpinned and placed upon iron girders, and the sewer, being there 9 feet 3 inches in diameter, was carried through the cellar without further injury to the house. The sewer is carried close under the bottom of Sir George Duckett's Canal, the distance between the soffit of the arch of the sewer and the water in the canal being only 24 inches. The bottom of the canal aud the top of the sewer are here formed of iron girders and plates, with a thin coating of puddle, and no leakage from the canal has taken place.

The Penstock Chamber, which is formed at the junction of the High and the Middle Level Sewers at Old Ford, Bow, is provided with five large iron penstocks worked by machinery, by which the sewage can be diverted at will either into the two lower channels formed for the discharge of the storm-waters into the River Lea, or into the two upper channels constructed over that river, and forming the commencement of the Northern Outfall Sewer. As a rule the lower channels will be closed, and the sewage will flow through the two upper channels to Barking Creek; but in times of heavy rain, as soon as the waters have risen to the top of the upper channels, the surplus will flow over five weirs, constructed in the chamber, into the lower channels, and be discharged by them into the Lea. In case of any sudden accident to the intercepting sewers, the whole of the sewage could, by raising the lower penstock, be diverted in a few minutes into the Lea.

The penstock and weir chamber is a novel arrangement, which has proved to be simple and satisfactory in its operation, and it places three-fourths of the Northern sewage completely under command. It is built in brickwork, is about 150 feet in length, 40 feet in breadth, and, in places, 30 feet in height.

The Middle Level Sewer is carried as near to the Thames as the contour of the ground will permit, with the object of intercepting as much sewage as possible by gravitation, and of reducing to a minimum the low level area which is dependent upon pumping. The area intercepted by this sewer is 17½ square miles in extent, and is densely inhabited. The sewer commences near the Harrow Road at Kensal Green, passes under the Paddington Canal into the Uxbridge Road at Notting Hill, along Oxford Street, Hart Street, Liquorpond Street, and across Clerkenwell Green;

thence by way of Old Street Road to High Street, Shoreditch, along Church Street, Bethnal Green Road, and Green Street, under the Regent's Canal, and the North London Railway, to a junction with the High Level Sewer at the Penstock Chamber at Bow. In order to enlarge the area drained by gravitation, a branch, 4 feet by 2 feet 8 inches, with a fall of 4 feet per mile, is carried along Piccadilly, passes through Leicester Square and Lincoln's Inn Fields to the main line at King's Road, Gray's Inn Road. The length of the main line is about 9½ miles, and of the Piccadilly Branch 2 miles, besides which there are minor branches and feeders. The fall of the Main Sewer varies from 17½ feet per mile at the upper end, by a gradual reduction, to 2 feet per mile at the lower end.

The sizes vary from 4 feet 6 inches by 3 feet, to 10 feet 6 inches in diameter, and lastly to 9 feet 6 inches by 12 feet at the outlet. About 4 miles of the main line, and the whole of the Piccadilly Branch, were constructed by tunneling under the streets, at depths varying from 20 feet to 60 feet. This sewer is formed mostly in the London clay; to the east of Shoreditch it is constructed through gravel, and during the execution of the works under the Regent's Canal, the water burst into the sewer, fortunately giving sufficient warning to prevent any loss of life. The sewer was afterwards constructed under the canal, first by enclosing one-half of the width of the tunnel at a time within a coffer-dam, and then by open cutting.

The Middle Level Sewer is carried over the Metropolitan Railway by a wrought-iron aqueduct of 150 feet span, weighing 240 tons; the depth of construction between the under side of the aqueduct and the inverts of the double line of sewers being only 2½ inches. As the traffic of the railway could not be stopped during the construction of the

aqueduct, which is only a few inches above the engine chimneys, the structure was built upon a stage, at a height of 5 feet above its intended ultimate level, and was afterwards lowered into place by means of hydraulic rams. This stage was necessarily of great strength and was carefully constructed; the sewers being formed by wrought-iron plates riveted together.

The Middle Level Sewer is provided with weirs, or storm-overflows, at its various junctions with all the main valley lines.

The Low Level Sewer, besides intercepting the sewage from the low level area, which contains 11 square miles, is also the main outlet for a district of about 14½ square miles, forming the western suburb of London, which is so low, that its sewage has to be lifted at Chelsea a height of 17½ feet, into the upper end of the Low Level Sewer. This sewer commences at the Grosvenor Canal, Pimlico, and passes along Lupus Street and Bessborough Street, to and along the river side from Vauxhall Bridge. From Westminster Bridge to Blackfriars it is formed as part of the Thames Embankment. It is tunneled under the River Lea, on its route to the Abbey Mills pumping station, where its contents are raised 36 feet by steam power. It has two branches:—one from Homerton, and the other from the Isle of Dogs. This island was formerly a dismal marsh, and received its name from the circumstance of the king's hounds having been kept there, when the Court was at Greenwich. Its is now the site of extensive factories and works, and is largely populated by artisans and workmen. Its drainage can only be perfected by the aid of pumping, The length of the main line is 8¼ miles, and its branches are about 4 miles in length. Its size varies from 6 feet 9 inches to 10 feet 3 inches in diameter, its inclination ranges

from 2 feet to 3 feet per mile, and it is provided with storm-overflows into the river.

The Western Division includes Fulham, Chelsea, Brompton, Kensington, Shepherd's Bush, Hammersmith, and part of Acton. It was originally intended to deodorize, or utilize, the sewage of this district in its own neighborhood, rather than to incur the heavy cost of carrying it to Barking, and lifting it twice on its route to that place. But strong objections to this having been raised, the latter and more costly plan has since been adopted, and now forms part of the Low Level system of drainage.

The Chiswick Line commences at Chiswick Mall, and passing near to the river and along the Fulham Road, and Walham Green, again skirts the river and extends to the pumping station near the Grosvenor Canal.

The Fulham branch commences at Fulham Bridge, and joins the Chiswick line at the King's Road.

The size of the main line varies from 4 feet by 2 feet 8 inches to 4 feet 6 inches in diameter, with a fall of 4 feet per mile, the depth below the surface being from 14 feet to 30 feet. The branch varies in size from 3 feet 9 inches by 2 feet 6 inches to 4 feet 6 inches by 3 feet, its fall being 10⅓ feet per mile, and its depth about 17 feet.

The Acton branch is carried along the Uxbridge Road from the Stamford Brook to the Counters Creek Sewer at Royal Crescent, Notting Hill, into which it diverts the water from the higher ground, and which forms a storm-outlet into the Thames, near Cremorne Gardens. The Uxbridge Road Sewer varies from 3 feet 9 inches by 2 feet 6 inches to 4 feet by 2 feet 8 inches; it has a fall of 4 feet per mile, and is about 14 feet deep.

The Chiswick Sewer is 3¼ miles long, the Fulham Sewer 1 mile·720 feet, and the Acton branch 1½ miles.

The works were executed mainly through gravel, charged with such large volumes of water that it was necessary to lay stone-ware pipes under the inverts of the sewers, to lower the water in the ground, and to convey it to numerous and powerful steam-pumps in the line of the works, before the sewers could be constructed. The operation of passing under railways and canals, difficult in so treacherous a subsoil, was successfully accomplished, and no serious accidents or failures occurred.

The Northern Outfall Sewer is a work of peculiar construction; as, unlike ordinary sewers, it is raised above the level of the surrounding neighborhood in an embankment, which has the appearance of a railway embankment, and it is carried by aqueducts over rivers, railways, streets and roads. Rails upon which the contractors' steam-engines and trucks have been constantly travelling, are at the present time laid along the top of it. It commences by a junction with the High and Middle Level Sewers, at the Penstock Chamber at Bow, and passes immediately under the rails of the North London Railway, which are carried over it on girders. It then passes under Wick Lane, which has been raised 18 feet, and then over the River Lea by a wrought-iron aqueduct of 57 feet span. This aqueduct consists of two wrought-iron culverts of the same section as the brick sewers, and over these is formed a roadway with parapet walls, the whole being supported by three wrought-iron plate girders. Indeed, all the aqueducts on this line of sewer are so constructed as to carry a wide roadway upon plates and girders on the top of them. Four other streams between the River Lea and the Stratford Road are crossed over by iron tubes, of spans varying from 18 feet to 45 feet; and the sewers pass close under the rails of the Eastern Counties Railway, where it is on an embank-

ment, the work having been executed without any interference with the traffic on the railway. The Outfall Sewer, up to this point, consists of two culverts, each 9 feet by 9 feet, placed side by side, formed with upright sides, semicircular crowns and segmental inverts. These are built upon a solid concrete embankment, carried through the peat soil down to the gravel, which is in many places at a great depth below the surface. Concrete is also carried up with a slope of 1 to 1, so as to form an abutment to the sides of the sewers. The whole structure is then covered with an earthen embankment, with slopes of 1½ to 1, the foot of which is fenced in by a quick-set hedge and a ditch, and presents the appearance of a simple railway embankment. It is executed of sufficient strength to carry a railway or a roadway on the top, and will no doubt, at a future time, be used for some such public purpose. The outer earthen embankment not being carried below the surface, has from time to time subsided into the peat marshes through which it is formed, and these settlements have been made good in the ordinary manner; but the sewer and its concrete embankment have shown no sign of settlement or fracture since their completion. At the Stratford Road, the top of the sewer was depressed and carried under the road by four culverts, each 6 feet high and 7 feet 3 inches wide, covered with cast-iron plates. A large amount of property was purchased, and the road raised 10 feet upon a viaduct to pass over the sewer at an inclination of 1 in 50. From the Stratford Road the double line of sewer is continued over Abbey Mill Lane, by two self-supporting wrought-iron tubes, to the Abbey Mills pumping station, where the contents of the Low Level Sewer will be raised 36 feet. From this point three parallel lines of sewer, of the same form and dimensions as those before described,

are continued to the outlet at Barking Creek. Gates and overflow weirs are formed in the line of these culverts, enabling the sewage to be turned into either or all of them at will, and preventing any one of them being at any time overcharged. Just beyond the pumping station the three lines pass over the Channelsea River and Abbey Creek by cast-iron culverts, supported by four wrought-iron plate girders of two spans of 40 feet each. They are then carried over Marsh Lane, the North Woolwich and the Bow and Barking Railways, by aqueducts somewhat similar to those already described. These railways were lowered to enable the sewer to pass over them; for the sewer being reduced to a minimum uniform fall of 2 feet per mile, could not be raised or depressed like a railway to accommodate its levels to those of previously existing works. This, indeed, constituted one of the great difficulties experienced in laying out the line of the Outfall Sewer, for the district through which it passes was already closely intersected by public works. For the same cause, also, the thickness of the ironwork between the bottom of the sewer and the under side of the aqueduct was reduced to a minimum, and it does not in most cases exceed 5 inches.

For a distance of about 1½ miles at the lower end of this sewer, so great was the depth of the peat in the marshes, that it would have been very costly to have excavated the whole of the ground down to the gravel, and to have filled it in with solid concrete. The plan therefore adopted for the foundations of this length, was to excavate cross trenches 6 feet 6 inches wide, at distances of 21 feet from each other, down to the solid ground, and to fill these in with concrete piers, upon which brick arches of four rings in thickness were turned, and the sewers were built upon these arches.

The top of the bank is 40 feet wide, and in some cases 25 feet above the level of the marshes.

From the crossing of the Bow and Barking Railway, the triple sewer is constructed in brickwork to its outlet at Barking Creek; crossing in its route the five following roads, viz.: Balaam Street, Plaistow, Barking Road, Prince Regent Lane, Blind Lane, and East Ham Hall Manor Way, which were raised for the purpose 6 feet, 8 feet, 13 feet, 20 feet, and 16 feet, respectively.

The invert of the sewer at the outlet is about 18 inches below high-water mark; but before entering the river, the sewage falls over an apron a depth of 16 feet, and is discharged by nine culverts, each 6 feet high by 6 feet wide, laid at the level of low-water spring-tides. The three upper sewers are, however, fitted with penstocks before reaching the tumbling bay, to afford the means of closing the river outlet, and of diverting the sewage into the reservoir, in which it will be stored for about eleven hours per tide. The reservoir is so situated that the sewers form one side of it, and a communication is made between them by sixteen openings, through which, when the penstocks are closed, the sewage enters the reservoir, and is there stored until high water. The sluices at the lower part of the reservoir are then opened, and allow the sewage in the reservoir to be discharged into the river through the nine 6-feet culverts; and the three penstocks at the river outlet being opened at the same time, the sewage is simultaneously discharged directly into the river from the outfall sewers without being first passed through the reservoir. The upper openings from the outfall sewer into the reservoir are also fitted with sluices, to enable the communication between the sewer and the reservoir to be shut off in cases of necessity, and the whole of the waters to be discharged over the tumbling

bay. At the river end of the nine culverts a channel is cut in the bed of the river, the floor of which is formed of concrete, and the sides protected by campsheathing, so that the sewage is discharged into the bed of the river at the time of high water.

The Barking Reservoir is 16¾ feet in average depth, and is divided by partition walls into four compartments, covering altogether an effective area of 412,384 superficial feet, or about 9½ acres. The external and partition walls are of brickwork and the entire area is covered by brick arches, supported on brick piers, the floor being paved throughout with York stone. The reservoir being almost entirely above the general surface of the ground, is covered by an embankment of earth rising about 2 feet above the crown of the arches. The ground over which it is built being unfit to sustain the structure, the foundations of the piers and of the walls were carried down in concrete to a depth of nearly 20 feet.

The sewage is ordinarily prevented rising above a certain level in the reservoir by means of a weir or overflow in the partition walls, which are built hollow, the spaces communicating with the discharging culverts below the outfall sewers. In cases of necessity, however, the reservoirs can be filled above the weir level by closing the penstocks fitted to the discharging culverts at their entrance into the tumbling bay before referred to. A culvert communicating with the river is built at the back of the reservoir, having openings into each compartment fitted with penstocks, and by these means any one of the compartments may be filled with tidal water at the top of the tide, and be flushed out by its discharge at the period of low water.

The Abbey Mills Pumping Station will be the largest establishment of the kind on the Main Drainage Works,

providing, as it does, engine power to the extent of 1,140 H.P., for the purpose of lifting a maximum quantity of sewage and rainfall of 15,000 cubic feet per minute a height of 36 feet.

The engine-power is here divided among eight engines, each being equivalent to 142 H.P. Each engine is furnished with two boilers, making sixteen boilers in all. The engines are contained in one building, cruciform in plan, and are arranged in pairs, two engines in each arm of the cross. These engines, as in all the other pumping establishments on these works, are expansive, condensing, rotative beam engines, but are somewhat more powerful than those used elsewhere, the cylinders being 4 feet 6 inches in diameter with a length of stroke of 9 feet. The pumps differ also in being double-acting, a circumstance which allows of the air-pump, etc., being worked from the main beam, instead of from a distinct beam, as at the other stations. Each engine works two pumps, having a diameter of 3 feet 10½ inches and a length of stroke of 4½ feet. The boilers are each 8 feet in diameter, and 30 feet long, with double furnaces.

The engine-house is divided in height into three compartments, the lower one being the pump-well, into which the sewage is conveyed from the Low Level Sewer, the intermediate one forming a reservoir for condensing water, and the upper being more correctly the engine-house, in which are contained the eight engines. The lower part of this building is laid about 3 feet above the bottom of a thick stratum of clay, overlying a considerable thickness of sand with water, through which the foundations are carried, by piling, on to a bed of firm gravel below. The boiler-houses and other portions of the work are founded upon the clay stratum overlying the sand. As these deep foundations are

situated in close proximity to the Northern Outfall Sewer, which is contained in an embankment above the general level of the ground, great caution was requisite to prevent any settlement in that sewer. The boiler-house and coal-stores are built between the outfall sewer and the engine-house, keeping the deep excavations as far distant from the sewer as practicable. The coal-stores are built with their floors level with the stoke-holes in the boiler-house, and tramways laid from one to the other; one side of the coal-stores forming also the front side of the boiler-house. This floor is only slightly below the present surface of the ground, which is 6 feet below high water.

The sewage from the Low Level Sewer, before entering the pump-wells, passes through open iron cages, the bars of which intercept any substances likely to interfere with the proper action of the pump-valves; and the cages, when requisite, will be lifted above ground, by proper gearing, and the intercepted matter discharged into trucks, or otherwise removed. The sewage will then pass into the wells, and be lifted by the pumps, through hanging valves, into a circular culvert of cast iron, and thence forced into any of the three culverts forming the Northern Outfall Sewers.

THE SOUTH SIDE OF THE THAMES.

The High Level Sewer and its Southern Branch, correspond with the High and the Middle Level Sewers on the North side of the Thames. The Main Line commences at Clapham, and the Branch Line at Dulwich, and they together drain an area of about 20 square miles, including Tooting, Streatham, Clapham, Brixton, Dulwich, Camberwell, Peckham, Norwood, Sydenham, and part of Greenwich. Both lines are constructed of sufficient capacity to carry off all the flood-waters, so that they may be entirely

intercepted from the low and thickly-inhabited district, which is tidelocked and subjected to floods. The storm-waters will be discharged into Deptford Creek, whilst the sewage and a limited quantity of rain will flow by four iron pipes, each 3 feet 6 inches in diameter, laid under its bed into the Outfall Sewer.

The two lines unite in the New Cross Road, near to the New Cross Station on the Brighton Railway, and they are constructed side by side along that road to Deptford; but at the New Cross Station, the Branch Line is 10 feet above the Main Line, but by falling at a more rapid inclination, it arrives at the same level as the Main Line at Deptford Broadway. The Branch is 4½ miles in length, of which 1,000 feet were executed in tunnel, at depths varying from 30 feet to 50 feet. Its size varies from 7 feet in diameter to a form 10 feet 6 inches by 10 feet 6 inches, with a circular crown and segmental sides and inverts, and its fall varies from 30 feet per mile at the upper end, to 2⅓ feet per mile at the lower end. The soil through which it passes is mostly a mixture of sand and clay, containing cockle and other shells to a large extent. The old Effra Sewer, which fell into the river near Vauxhall Bridge, has been diverted through this sewer to a new outlet at Deptford, and the old line has been filled in and abandoned. Two subsidiary branches have been extended from this sewer at Dulwich —the one to Crown Hill, Norwood, and the other to the Crystal Palace.

The Main Line varies in size from 4 feet 6 inches by 3 feet at the upper end, to 10 feet 6 inches by 10 feet 6 inches, of the same form as the branch by the side of which it is constructed. The double line of sewer occupies the whole width of Church-street, Deptford, and the inverts being below the foundations of the houses on each side of the

street, the walls of the houses were underpinned, and the spaces between them and the sewers filled in with concrete. The subsoil here consisted of loamy sand and gravel with large quantities of water, and, to add to the difficulty of the work, the old Ravensbourne Sewer, which passed through the centre of the street, had to be taken up, and its waters diverted during the progress of these operations.

The outlets of the two sewers, 10 feet 6 inches by 10 feet 6 inches, are each fitted with two hinged flaps, one above the other, the lower one being usually fixed close, so as to form a dam to drive the waters through the iron pipes into the Outfall Sewer, but the upper one hanging free, in order to serve as a tide-flap, and allow of the exit of the sewage into the Creek, when it rises in the sewer to a sufficient altitude. In cases of heavy floods, however, the lower flap can be opened, to admit of a free and full discharge from the sewers into the Creek. The entrances to the iron pipes are in troughs, or sumps, in the large sewers, a short distance within or behind the outlet flaps, and are fitted with penstocks, to shut off the sewage from the Outfall Sewer in case of need.

The falls of the Main Line are at the upper end 53 feet, 26 feet, and 9 feet per mile to the Effra Sewer at the Brixton Road, and thence to the outlet $2\frac{1}{3}$ feet per mile. The sewer is executed in brickwork, varying in thickness from 9 inches to $22\frac{1}{2}$ inches, one-half, that forming the invert, being in Portland cement, and the remainder in blue lias mortar.

The Low Level Sewer does not follow the course of the River, as on the North side, but, commencing at Putney, it takes a more direct line, through low ground once forming the bed of a second channel of the Thames, and drains Putney, Battersea, Nine Elms, Lambeth, Newington, Southwark, Bermondsey, Rotherhithe, and Deptford, comprising

an area of 20 square miles. The surface of this area is mostly below the level of high water, and is in many places 5 feet or 6 feet below it, having at one time been completely covered by the Thames. The sewers throughout the district have but little fall, and, except at the period of low water, were tide-locked and stagnant; consequently, after long-continued rain, they became overcharged, and were unable to empty themselves during the short period of low water. The waters, therefore, were constantly accumulating, and many days frequently elapsed, after the cessation of the rain, before the sewers could be entirely relieved, the sewage in the interim being forced into the basements and cellars of the houses, to the destruction of much valuable property. The want of flow also caused large accumulations of deposit in the sewers, the removal of which was difficult and costly. These defects, added to the malaria arising from the stagnant sewage, contributed to render the district unhealthy; and it was with reference to the condition of this district that the late Mr. R. Stephenson and Sir W. Cubitt so forcibly described the effect of artificial draining by pumping, as equivalent to raising the surface a height of 20 feet.

The Low Level Sewer has, in fact, rendered this district as dry and as healthy as any portion of the Metropolis. Its length is about 10 miles. Its size varies from a single sewer 4 feet in diameter at the upper end, to two culverts, each 7 feet high by 7 feet wide, at the lower end, and its fall ranges from 4 feet to 2 feet per mile. The lift at the outlet of the sewer is 18 feet. This sewer was constructed through a stratum of sand and gravel overlying the clay, such as is frequently found in the beds of rivers, and copiously charged with water. Some very successful instances of tunnelling under canals, railways, and house property,

occurred in the construction of this work; and a mode of pumping in a quicksand, and rendering it dry and firm without drawing off the sand, was adopted. Much difficulty was experienced in executing a portion of this work close to and below the foundations of the arches of the Greenwich Railway, and under Deptford Creek, owing to the large volume of water there met with. This was, however, at last surmounted, by sinking two iron cylinders, each 10 feet in diameter, through the sand, to a depth of about 45 feet, the water being kept down by pumping, at the rate of from 5,000 gallons to 7,000 gallons per minute. The sewer was carried under Deptford Creek, and the navigation was kept open, by constructing a coffer-dam into the middle of the Creek, and by executing one-half of the work at a time. All these works were completed with but few and unimportant casualties.

The sewers of this district had been constructed, generally, with a fall from west to east, and had been connected with each other in such a manner that, in case of one becoming first overcharged, it might be relieved by its neighbor, and the sewage be reduced to a uniform level all over the district. Taking advantage of this circumstance, an important branch was constructed from the Low Level Sewer at High Street, Deptford, towards the river to St. James's Church, Bermondsey. This branch, by intersecting the Earl, the Duffield, and the Battle Bridge Main Sewers, relieves a large and populous district. Its length is about 2 miles, its size varies from 5 feet to 5 feet 6 inches in diameter, and its fall is 4½ feet per mile. Its depth varies from 15 feet to 40 feet below the surface.

The Deptford Pumping Station is situated by the side of Deptford Creek, and close to the Greenwich Railway Station. The sewage is here lifted from the Low Level

Sewer, a height of 18 feet, into the Outfall Sewer. An iron wharf wall and barge bed 500 feet long has been constructed at the side of the creek, and is provided with a crane and tramways for landing coal or other materials. Four expansive, condensing, rotative beam engines, each of 125 H.P., and capable together of lifting 10,000 cubic feet of sewage per minute a height of 18 feet, are here constructed. These engines are worked by ten Cornish singled-flued boilers, each 30 feet long and 6 feet in diameter. The cylinders are 48 inches in diameter, with a length of stroke of 9 feet, and the pumps, two of which are worked by one engine direct from the beam, are single-acting plunger pumps, the diameter of the plungers being 7 feet and the length of the stroke 4½ feet. One pump is placed on the beam, midway between the steam cylinder and the centre pillars, and the other midway between the centre pillars and the fly-wheel. The air, the feed, and the cold water pumps are actuated by a separate beam, attached to the cylinder end of the main beam. The pump-valves are leather-faced hanging valves, and the sewage is discharged through them into a wrought-iron culvert placed on the level of the Outfall Sewer, and connected with it by a brick culvert, which receives also the sewage from the High Level Sewer, previously brought by gravitation under the creek, through four cast-iron pipes 3 feet 6 inches in diameter. Both streams enter the Outfall Sewer, and are together conveyed to Crossness, where they are again lifted. The chimney shaft at this station is 7½ feet in diameter at the base and 6 feet at the top; its height is 150 feet, and the furnaces draw from the sewers and the engine-well to assist in the ventilation of the works. The accommodation for coals is ample, the sheds covering an area of 18,000 superficial feet.

Provision is made by gratings for the interception of the

larger substances brought down by the sewers in the same manner as at Crossness.

The Southern Outfall Sewer conveys the sewage which flows into it from the High Level Sewer by gravitation through the four iron culverts laid under Deptford Creek, and that which is pumped into it from the Low Level Sewer from Deptford through Greenwich and Woolwich to Crossness Point in the Erith Marshes. It is not, like the Outfall Sewer on the North side, constructed above the level of the ground, but is entirely under ground for its whole length of $7\frac{3}{4}$ miles. It is 11 feet 6 inches in diameter, formed in brickwork generally 18 inches thick, and has a fall of 2 feet per mile. The bottom of the sewer is 9 feet below the level of low water at its outlet into the river, so that it can discharge into the river at and near to low water by gravitation, in case of necessity; but ordinarily the mode of discharge will be by pumping into the Crossness Reservoir. It has been constructed at a depth of about 16 feet below the surface, except through Woolwich, where the depth ranges from 45 feet to 75 feet. The soil through which it passes is mostly gravel and sand, but the Woolwich tunnel, which is the principal feature of the work, is partly in the chalk. One mile of this tunnel was executed under the town of Woolwich without any casualties or settlements.

The outfall of the sewage on the South side of the Thames is at the Crossness Reservoir and Pumping Station. The sewage is discharged into the river at the time of high water only, but the sewer is at such a level that it can discharge its full volume by gravitation about the time of low water. Its outlet is ordinarily closed by a penstock placed across its mouth, and its contents are raised by pumping into the reservoir, which is built at the same level as that on the North side; and like it, it stores the sewage except

for the two hours of discharge after high water. The sewage is thus diverted from its direct course to the river into a side channel leading to the pump-well, which forms part of the foundation for the engine-house; from this well it is lifted by four beam engines, each of 125 H.P., and actuating direct from the beam two compound pumps, each having four plungers. The engines are condensing, rotative beam engines, the cylinders being 4 feet in diameter, with a length of stroke of 9 feet; they are situated at the end of the main beam, which is 40 feet in length, the fly-wheel connecting-rod being attached to the further extremity, and the pump-rods situated on either side of the beam centre. The air, the feed and the cold-water pumps are actuated by a separate or counter-beam fixed at one end to a rocking lever, and attached at the other to the main beam. The cylinders are supplied from twelve Cornish boilers, each 6 feet in diameter and 30 feet long, having an internal furnace and flue 3 feet in diameter, and being set so as to have the second heat carried with a split draught along the sides, and the third heat under the bottom of the boiler into the main flue leading to the chimney.

The maximum quantity of sewage to be lifted by these engines will ordinarily be about 10,000 cubic feet per minute; but during the night that quantity will be considerably reduced, while on the other hand it will be nearly doubled on occasions of heavy rainfall. The lift also will vary from 10 feet to 30 feet, according to the level of water in the sewer and in the reservoir into which it is lifted. These variable conditions of working led to some difficulty in the arrangement of the engines and pumps, which it has been endeavored to meet by the arrangement of pump plungers before alluded to. The pumps, which are single-acting, are placed equidistantly on each side of the beam

centre, the pump cases being each 12 feet in diameter, fitted with four plungers 4 feet 6 inches in diameter. These plungers are placed in pairs, each pair being worked from a cross-head on the main beam, which is in two flitches with this object, and arrangements are made for throwing either pair of plungers out of gear. By these means the capacity of the pumps may be varied in the proportion of 1, 2, or 3, as the inner pair, outer pair, or both pairs are thrown into gear. The sewage is discharged into a wrought-iron trough, through hanging leather-faced valves, which are suspended from wrought-iron shackles, and fitted with the wrought-iron back and front plates. Each valve is 12 inches by 18 inches. It should be mentioned, that substances which might prevent the proper action of the valves are intercepted before reaching the pumps, by a wrought-iron grating placed in front of the openings to the pump well, the substances so intercepted being lifted from the face of the grating by an endless chain, with buckets or scrapers and combs attached, working vertically in front of and in close contact with the grating, the teeth of the comb passing between the bars. On the descent of the chain, the buckets are overturned and discharge their contents into a trough, from which they will be removed by manual labor.

The sewage, after being delivered from the pumps into the wrought-iron trough, is discharged through brick culverts into the reservoir, or, in case of need, provision is made for its discharge through other culverts directly into the river. After being stored in the reservoir until the time of high water, the sewage is discharged by a lower set of culverts into the river. There are two tiers of eight openings in each compartment of the reservoir, the upper eight for the admission of the sewage from the pumps to the reservoir, and the lower eight for its discharge into the

river, the apertures in all cases being opened and closed by penstocks.

The reservoir, which is 6½ acres in extent, is covered by brick arches supported on brick piers, and is furnished with weirs for overflows, and with a flushing culvert. Its height, level, and general construction are similar to that at Barking Creek, already described. Over the reservoir are built twenty-one cottages for the engineers and other persons employed upon the works.

The ground upon which the whole of these works were constructed consists of peat, sand, or soft silty clay, and affords no sufficient foundation within 25 feet of the surface. To obviate this difficulty and to reduce the expense of the foundations as much as possible, the culverts on the various levels were built, as far as practicable, in the same trenches, one above the other; the lowest, leading from the Outfall Sewer to the pump-wells, support those discharging the sewage from the reservoir, which latter in turn support those leading from the pumps into the reservoir. The requirements of the pump-wells necessitated that the walls of the engine-house should be carried down to the level of the gravel independently of the nature of the ground; but such was not the case with the boiler-house. The boilers and stoke-hole floor are supported on arches, which spring from walls brought up from the gravel, and the space below the boiler-house floor is made available as a reservoir for condensing water. The water from the hot and cold wells of the engines is conveyed hither, and one compartment is set apart as a chamber for cooling the water from the hot well previous to its being used again for condensing water. With the same object of saving separate foundations, coal-stores and workshops have been erected, partly on the external walls of the reservoir and partly on the culverts

in front of them, large coal-stores being also provided in front of the boiler-house, and on a level with the stoke-holes, into which the coals will be brought on tramways. A tramway is also provided for the upper level coal-sheds, on the level of the tops of the boilers, whence the coals will be shot into the stoke-holes below. Tramways are also laid from the coal-sheds to the river, and jetties are carried out into the river to facilitate the landing of coals and their transfer to the stores. A wharf wall has been constructed along the river frontage of the works for a distance of about 1,200 feet, by which a large portion of the "saltings" has been reclaimed. The wall is of brick, carried upon brick arches, which rest upon piers formed of iron caissons filled with concrete, and which are carried down to the gravel.

The chimney into which the flues from the boilers are conveyed is square on plan externally, being 8 feet 3 inches internal diameter throughout, and 200 feet in height; it is founded upon a wide bed of concrete, brought up from the gravel, which is here 26 feet below the surface.

The reservoir, as well as the several culverts and the pump wells, are all connected by flues with the furnaces of the boilers, for the purposes of ventilation, in a manner similar to that adopted at the Deptford and other pumping stations.

The outlet into the river from the Outfall Sewer, which was constructed in connection with these works, consists of twelve iron pipes, each 4 feet 4 inches in diameter, carried under the "saltings" into a paved channel formed in the bed of the river. These pipes are gathered into the single sewer, by culverts in brickwork on the land side of the wharf wall, the culverts being gradually reduced in number, and their dimensions increased, as they approach the junction with the large Outfall Sewer.

The tunnels successfully completed, under circumstances of difficulty, and where failure would have been very disastrous, were numerous.

The tunneling, and the formation of the sewers through quicksands charged with large volumes of water, existing under various portions of the metropolis, but more particularly in the low-lying districts on the south side of the Thames, were rendered practicable and safe by a mode of pumping the water out of the ground without withdrawing the sand, which was adopted and perfected during the progress of these works.

During the author's early connection with the Metropolitan Sewers, several disastrous results of pumping in quicksands had occurred, in consequence of the withdrawal of the sand from under the foundations of the adjoining houses. This caused unequal settlements and fissures in the walls, so that the buildings had eventually to be pulled down and rebuilt.

The sewers in the streets in the neighborhood of Great George Street, Westminster, being in peat and sandy soils charged with water, were not formed without considerable risk.

The cases are too numerous to be here mentioned, but a few of the more prominent may be alluded to. The line of tunnel from Kennington Church to the Old Kent Road, a distance of about 1,000 feet, is close under the basements of a large number of houses, the top of the tunnel being only from 10 feet to 12 feet below the surface, and the diameter being about 10 feet. The water was pumped out of the sand, for this length of tunnel, at the rate of about 8,000 gallons per minute. The same sewer was carried, through similar soil, under the Grand Surrey Canal, and within 8 feet of the water in it; and again under the same canal in

the Deptford Lower Road, where the distance between the top of the tunnel and the water in the canal was only 6 feet 4 inches, the whole of the soil being gravel and sand, with 1 foot of puddle in the bottom of the canal.

The Regent's Canal in the Caledonian Road was also tunnelled under, the distance between the top of the tunnel and the water in the canal being only 2 feet, so that the miners could hear the barges as they passed over their heads scrape against the ground; this was, however, executed in clay. Another tunnel has been formed 33 feet under the rails of the West London Railway, and under the Kensington Canal. Sewers were constructed under the London and Brighton, the North Kent, and several other railways, without any interruption to the continuous traffic on them.

The method adopted for pumping out the water, without drawing off the sand, and for building the brickwork in ground so charged with water, was first to sink, in some convenient position, near the intended works, a brick well to a depth of 5 feet or 6 feet below the lowest part of the excavation. In some cases, where the depth was great, an iron cylinder was sunk below the brickwork, and the bottom and sides of the well were lined with shingle, which filtered the water passing into it, and exposed a large surface of this filtering medium. Earthenware pipes were carried from this well and laid below the invert of the intended sewer, small pits being formed at the mouths of these pipes, to protect them from the deposit. By these means, the water has been successfully withdrawn from the worst quicksands, and they have been rendered firm and dry for building on. Iron plates have, in olden times, been laid underneath the brickwork of the invert of the sewers, to support them in such treacherous ground, but concrete forms both a cheaper and a better foundation, and unless the ground is so dry and solid that it can be excavated to the exact form of the sewer

to be placed on it, there is no portion of the work more important than the effectual backing of the invert and the haunches with concrete.

The bricks used in the works are laid in blue lias lime mortar, mixed in the proportion of 2 of sand to 1 of lime for one-half or two-thirds of the upper circumference of the sewers, and the remainder has been laid in Portland cement, mixed with an equal proportion of sand. A very considerable length of sewer has been laid entirely in cement. A double test of the quality of the cement has been used, which has been found most effective, and has tended greatly to improve the manufacture of that material, so important in building operations. The specifications provide, that the whole of the cement shall be Portland cement of the very best quality, ground extremely fine, weighing not less than 110 lbs. to the bushel, and capable of maintaining a breaking weight of 500 lbs., on $1\frac{1}{2}$ square inch, seven days after being made in an iron mould, and immersed in water during the interval of seven days.

The total cost of the Main Drainage Works were about £4,100,000.

There are about 1,300 miles of sewers in London, and 82 miles of main intercepting sewers. The total pumping power employed is 2,380 nominal H.P.; and if at full work night and day, 44,000 tons of coal per annum would be consumed, but the average consumption is estimated at 20,000 tons.

The sewage on the North side of the Thames at present amounts to $11\frac{1}{2}$ million cubic feet per day, and on the South side to $5\frac{3}{4}$ million cubic feet per day; in addition to $28\frac{1}{2}$ million cubic feet of rainfall per diem on the North side, and $17\frac{1}{4}$ million cubic feet per diem on the South side, or a total of 63 million cubic feet per diem, which is equal to a lake of 482 acres, 3 feet deep.

B.

THE following notice to Bidders, and Specification for Building Sewers, is the result of many years experience in Brooklyn, and has from time to time received such modification as practice pointed out as desirable, and is submitted as embodying all the requirements essential to the construction of City Sewers:

Bidders will state a price per lineal foot for each section of the Brick Sewer, and each section of the Pipe Sewer separately, which price is to include all the excavation, whether hard-pan, quicksand, caves, boulders, or otherwise; also all plank used for sheet piling, or any timber used for supporting the banks or sides of the excavation; also all the repairs to the water-pipes or gas-pipes; also the filling in and ramming the earth around and over the Sewer and appurtenances, the removal and disposal of all rock, rubbish, or surplus earth dug out of the trenches, and taking up and removing the paving-stones and the earth and sand from the trenches to such part of the street or vicinity as may be directed by the Engineer; also all the relaying of flagging, curb, gutter and paving-stones, and all regrading rendered necessary by the construction of the work; also the preparation of the bottom where rock has been blasted out; also the cleaning out of the Sewer and Street Basins, and the removal of all rubbish immediately after the completions of each section; including also all loss or damage arising out of the nature of the work aforesaid, or from the action of the elements, or from

any unforeseen obstruction or difficulties which may be encountered in the prosecution of the same; also the furnishing of all necessary materials and labor, and the performance of the whole of the work mentioned in the specification and including all expenses incurred by or in consequence of the suspension or discontinuance of said work as before specified, or of a faithful compliance with each and every of the requirements of the agreement, and for well and faithfully completing the same and the whole thereof, in the manner therein specified.

Also the price for each Street Basin, with connecting shoot complete.

Also the price for each Manhole, complete.

SPECIFICATION.

Mode of Excavation.—The ground shall be excavated in open trenches to the necessary width and depth.

These trenches shall be opened one foot wider on each side than the exterior diameter of the Sewer intended to be built; the bottom of the trench being excavated to the exact form and size of the lower half of the Sewer which will be laid in it.

The work shall be backed in carefully, rammed and packed under and around the Sewer, with proper tools, by trusty persons approved by the Engineer.

Materials to be used in the Construction of Brick Masonry.—In the construction of the brick masonry, none but the best quality of whole North River bricks, burnt hard entirely through, shall be used, which are to be thoroughly wet immediately before being laid. Every brick is required to have full cement joints under bottom, sides, and ends, which for each brick is to be formed at one operation, and in no case is it to be made by working in the

cement after the brick is laid; every course of brick to be laid with a line. The bricks to be culled as they are brought upon the ground, and all bricks of an improper quality, and all bats, immediately removed from the same.

Cement Mortar.—The cement mortar is to be composed of the best quality of fresh hydraulic cement, mixed in the proportion of one barrel of cement to two barrels of clean, sharp sand, free from loam.

The material shall be carefully mixed as wanted, fresh for the work in hand, and no mortar used which shall be found to be weak or imperfect, from whatever cause.

Part of Street Work to be Built in.—The work under this agreement to be prosecuted at and from as many different points, in such part or parts of the Avenue or Street on the line of the work, as the Engineer may, from time to time, during the progress of the work, determine.

Description of Main Sewer.—The Main Sewers to conform in shape and dimensions to the cross-sections marked ——— on the plan now on file in the office of the Engineer.

All sections of the Main Sewer to be of brick, of the thickness shown on plan. The bricks of the inverted arch to be carefully and neatly laid, in full beds of cement, to the required curve, and so as to connect properly with the upper arch.

The upper arch in all the sections to be of brick, of the thickness shown on plan. The crown of the arches to be properly keyed with stretchers, the joints to be well filled with cement mortar. The whole of the brick masonry of the Sewer to be laid in cement mortar, made as before described. The extrados of the upper arch in all the sections to be neatly plastered with cement mortar.

Stone Masonry.—The stone masonry of the haunch backing shall be built of sound and durable stones, of shape

and form to make neat and substantial work of this class, laid in hydraulic cement mortar, of the quality already described, every joint and space being well filled with mortar. No stone to be less than one square foot in area on the bed, nor less than four inches thick, except the spalls and small stones necessary in building this class of work.

Any boulder or water-worn stone that may be used shall be shaped by the hammer to a good even bed, and so broken that no part shall present the original or bank surface.

House Connections.—Vitrified drain pipes, of six inches interior diameter, are to be worked in the walls of the Main Sewer, and all the branches or lateral Sewers connecting with the same, at an average distance apart of ten feet on all the lot fronts. These pipes are to be so set that the inner end will be flush with the inside of the Sewer at such height as the Engineer shall direct. Each pipe is to be closed by inserting an earthen cover therein at the hub end, similar to the pattern at the Engineer's office.

Foundation.—When, in the opinion of the Engineer, it may be necessary to place a foundation of grillage beneath the entire masonry, such foundation shall be made by the Contractor.

It will be formed of spruce plank, of a good quality, of such thickness and be laid in such manner as the Engineer shall from time to time, during the progress of the work, determine. The price to be allowed for the grillage will be Thirty Dollars per thousand feet, board measure, which price will include all the charges for extra digging for said grillage, and the cost of putting it in place.

Lateral Sewers.—The lateral Sewers to begin at the interior face of the Main Sewers heretofore described, and run through the streets laid down on said Sub-Division —,

Map "—," and together with the pipe Sewers and all connections, street basins and connecting shoots, manholes and other appurtenances, and all work of every kind and nature whatever to be done under this contract to complete the drainage of the said Sub-Division —, of Map "—," District Number — (—), shall be done according to the exhibits on the said Map "—," Sub-Division —, and the plans, models, and descriptions or specifications on file in the office, and in accordance with all the directions of the Engineer.

Stoneware Pipe.—For the 18-inch sewers, the pipes, junctions, reducers, curves, and all other pieces shall be of stoneware, sound and well burnt throughout their thickness; impermeable to moisture, and of smooth interior glazed surface; the joinings sound and true, and the whole free from cracks, flaws, blisters, and all other imperfections; circular in the bore; of true form in their lengths, whether straight or curved, internally of the full specified diameter, and of uniform thickness, except at junctions or on special pieces, where the thickness may be increased to meet the requirements of the case. The pipe used to be equal in all respects to the sample in the Engineer's office. All pipes to be $1\frac{1}{8}$ inches thick. The sleeves to be 5 inches wide, and $1\frac{1}{2}$ inches thick, and all sleeves to have an interior diameter of at least one inch greater than the exterior diameter of their respective pipes. The sleeve to be sound and well burnt, and of true figure, but need not be glazed. The junction branches and all other forms to conform correctly to the pattern, drawings, and directions furnished by the Engineer.

Cement Pipe.—The 15-inch cement pipe sewer shall be egg-shaped, and of capacity equal to a circle of 15 inches diameter in the clear. The hub to be not less than 3 inches deep. The thickness to correspond with the sample of egg-

shaped pipe to be seen at the Engineer's office. The 12-inch pipe shall be circular internally, of true form, and of the full specified diameter, the thickness to be not less than $1\frac{1}{2}$ inches, and the hub to be not less than 2 inches in depth. The outside shall be made flat on the bottom.

Manholes.—Manholes shall be constructed of such size and at such places as the Engineer may direct. They shall be built to conform to the plans of the same in the office of the said Engineer. In all cases an 8-inch arch, resting on a sand-joint of three-quarters of an inch in thickness, shall be turned over the pipes entering manholes; but the pipe entering a manhole shall not be set or laid until the foundation of the manhole is built and ready to receive it. All the walls to be built of brick, eight inches thick, and are to be worked up to within ten inches of the arch of the street, where the opening is to be two feet in diameter in the clear. A cast-iron manhole head and cover will be furnished, and is to be fitted to each of the above described manholes by the contractor. In all cases, the top surface of said manhole cover to be so set that it shall conform to the grade of the street when the street is repaved. The outside of all the manholes to be neatly plastered with cement mortar.

Basins.—Street Basins and connecting shoots more or less to be built where shown on the plan of the work, or at such points as the Engineer shall, during the progress of the work, determine and direct.

The Basin to be on the circular corner or side of the street, and to be constructed as shown on the plans on file at the office of the Engineer; each portion of the basin to be of the size and materials designated on said plans. The whole to be laid in cement mortar of the quality heretofore described. In case the nature of the ground be such that, in the opinion of the Engineer, timber ought to be substi-

tuted for the concrete foundation, as shown on the said plans, the timber shall be furnished and the foundation built of proper thickness and size, and the Contractor shall be allowed for all timber used in said foundations, Twenty-five Dollars per thousand feet, board measure. The iron pans for basins will be furnished by the City.

Maine or Connecticut granite only shall be used for the Street Basin heads, and to be of the form and dimensions shown on plans in the Engineer's office.

Shoots.—The shoots to connect the Street Basins with the Main Sewer shall be circular cement pipe of twelve inches in diameter, and to be in quality and dimensions the same as heretofore described, and to enter the Sewer at an angle, as shown on the plan, and to be well and truly laid and jointed as directed by the Engineer. The openings in the Sewer for the pipe to connect with to be workmanlike, and to be made and finished as the work progresses.

Right to Connect Lateral Sewers.—The right is reserved to connect any lateral Sewer or Sewers with the Sewer herein described, or to grant permits to any person or persons to make house connections therewith, at any time before it is finally completed; and said Contractor shall not interfere with or place obstructions in the way of such persons as may be employed in building such new Sewer or Sewers, or in making such connections; no extra allowance will be made to said Contractor on account thereof.

Old Sewers.—In case the line of this Sewer shall intersect with any Culverts now built, so much of said Culverts now built as in the opinion of the Engineer may be necessary, shall be taken up and rebuilt on a proper curve to connect with said Sewer; and the sum of ——— Dollars per running foot will be allowed for the part so rebuilt. No cutting of any Drain or Culverts which crosses the line

of the work, will be permitted in any case, except by and under the directions of the Engineer.

Removal of Rubbish.—During the progress of the work, and as fast as the same is completed, the Contractor shall immediately cart away all surplus earth, rubbish, and other materials from the Avenues or Streets.

Crosswalks.—The Crosswalks, wherever the same are disturbed, shall be taken up and relaid, on a bed of clean sharp sand, eighteen inches thick.

Any of these stones broken by the negligence of the Contractor, shall be replaced by good, sound stone, not less than four feet long, two feet wide, and eight inches thick throughout, the sides and ends to be truly squared so as to form close and even joints, smooth on the surface, and laid close.

Flagging.—Any of the Flagging broken during the progress of the work, to be replaced by good North River Flagging, equal to that now laid on the same sidewalks.

Intersections to be Repaved.—The Streets to be regraded and repaved, or remacadamized, as the case may be, to the extent which the aforesaid work may render necessary. All the cross gutters which may become unnecessary in consequence of the construction of any street basin, under this agreement, are to be taken up to a width of twenty (20) feet from curb to curb; then to be regraded in conformity with the grade of the street, and repaved in the manner before described, and so as to meet the requirements of the street basin aforesaid. In case it shall be found necessary to take up and reset any of the curb or gutter stones, or crosswalks at said intersections, so as to make the same conform to the proper grade, the same shall be considered as part of the work to be done under this contract, and no extra charge made for the same.

Obstructing Streets.—The Contractor will be required to observe all the ordinances of the Common Council in relation to obstructing the streets, keeping open passage-ways, and protecting the same where they are exposed, and would be dangerous to the public travel.

Refilling.—In refilling, the earth or sand to be well and faithfully rammed as the work progresses, with pavers' rammers, and in no case shall the number of men back-filling be more than twice the number of those ramming.

Length of Trench to be Opened.—In no case, from the commencement to the termination of the work aforesaid, without previous written permission from the Engineer, shall more than two hundred feet of trench be opened in advance of the complete building of the Sewer; and on the completion of each section of two hundred feet of Sewer, the regrading and repaving or remacadamizing, as the case may be, over the same shall be completed, and surplus earth, sand and rubbish on that section, immediately removed. The Sewer Basins and Shoots to be thoroughly cleaned out and left clean, before completion of the work embraced in this agreement.

Suspension of Masonry.—All work in masonry to cease positively on the first day of December in each year, unless the said Engineer shall otherwise direct, by a written notice, and not to be resumed until such time next thereafter as shall be designated by the aforesaid Engineer, and the construction of Pipe Sewers shall be suspended whenever directed by the said Engineer.

Upon the suspension of any work, as before mentioned, the trenches to be refilled and repaved, or remacadamized, as the case may be; and all materials, surplus earth, sand, rock, and rubbish removed from the street within three days thereafter, or they will be removed at the Contractor's expense.

Rock Blasting.—When rock is blasted out, it shall be taken out one foot below the grade of bottom of trench, and the trench shall then be filled with sand or gravel, to the level of grade, and thoroughly rammed and made solid. In all cases of rock blasting, the blast to be carefully covered with heavy timber, according to the ordinances of the Common Council relative to rock blasting, which ordinances shall be strictly observed; the material so excavated to be immediately removed from the street.

Where a line of main water-pipes intersects the line of the trench, any rock necessary to be excavated for a width of five feet in the clear on each side of the main pipe, is in all cases to be removed without blasting.

Connection with Drains.—The work aforesaid will not be considered as completed in accordance with this agreement, and therefore will not be received, in case any connections or drains are made and joined therewith, without permission in writing being obtained prior to the commencement of the construction of such connection or drains.

Rail Tracks.—In the progress of the work, the Contractor will be required to preserve from obstructions all rail tracks which may be affected by the prosecution of the work herein described; and also to afford the necessary facilities to the company or companies owning said tracks, or to their agents, in their preservation of the same from injury, without extra charge therefor.

Dismissal of Incompetent Persons.—If any person employed by the Contractor on the works should appear to the Engineer to be incompetent or disorderly, he shall be discharged immediately on the requisition of the Engineer; and such person shall not again be employed upon them without permission.

The Contractor shall not commence the works until due notice in writing has been given him.

Convenience of Traffic, etc.—The materials excavated shall be laid compactly on the side of the trench, and kept trimmed up, so as to be of as little inconvenience as possible to the public travel or the adjoining tenants. In case the street is not wide enough to throw the earth without stopping the passage-way on sidewalk, the Contractor shall, at his own expense, erect a board fence and keep a passage-way of two feet six inches open on said sidewalk.

Pumping, etc.—The Contractor shall, at his own expense, pump out, or otherwise remove, any water which may exist in the trenches, and shall form all dams or other works necessary for keeping the excavation clear of water during the progress of the works. In cases of running sand, or other bad or treacherous ground, the work shall be proceeded with day and night, without intermission, if the Engineer shall so direct.

Shoring of Excavations.—The sides of the excavation shall be supported with suitable plank and shoring, whenever necessary, but no allowance will be made therefor; in all cases the sheet piling to be drawn up as the work progresses, unless otherwise ordered by the written order of the Engineer, in which case the plank and shoring, so ordered to be left in the trench, will be measured and allowed for at the rate of Thirty Dollars per thousand feet, board measure.

Foundation for Pipes.—All irregularities in the trenches shall be filled up with gravel, firmly rammed in; but where the ground would not present a sufficiently firm foundation for the Pipes or Brick Sewers, the Contractor shall excavate to such increased depth as may be necessary, and shall make good to the required form and level with concrete, or

such other course shall be taken for securing a good foundation as the Engineer shall see fit to direct under the circumstances.

Mode of Laying Pipes.—The Pipes and Brick Sewers shall be laid truly in line and gradient throughout, according to the plans or directions furnished from time to time; and all curves, tapering pipes, junctions, syphons, and other pieces required, shall be properly excavated for and laid as directed. The end of all junctions laid for any future house-drain or other connection shall be closed up with a stoneware cap, to prevent the entrance of any dirt or materials. No extra allowance for putting in junction and capping.

Cleaning Pipes.—The interior of the pipe shall be carefully freed from all dirt and superfluous cement, as the work proceeds; for which purpose, a disc-plate mold, or other implement sufficiently long to pass two joints from the end of the pipe last laid, shall be continuously worked through.

Filling.—The earth on each side, and twelve inches over the Pipe, shall be carefully laid in, so as not to disturb them, tamped and solidly rammed down with proper rammers suited for the works. The trench shall then be filled in with layers of earth twelve inches deep at a time, each layer being well rammed over the whole surface with pavers' rammers. The first layer shall be placed over the pipes with a shovel, and not thrown from barrows.

Make Good all Connections.—The Contractor shall provide for the flow of sewers, drains, or water-courses, interrupted during the progress of the works, and shall restore or make good all connections, as may be directed, and shall immediately cart away or remove offensive matter, with such precautions as may be directed by the Engineer.

Superfluous Earth.—As the trenches are filled in, and

work completed, he shall cart away all superfluous earth or boulders and other materials from the spot, and leave all roads and places free, clear, and in good order, or they will be removed at the Contractor's expense, whenever the said Engineer shall so direct; but said Engineer shall allow twelve hours for said removal after written notification thereof has been given.

Repairing of Streets.—In case the Contractor should neglect or refuse to do any repairing, the Engineer shall also have the right to cause such repairing to be done at the Contractor's expense, after having given notice similar to that above specified. By clear and in good order, is meant the sweeping and cleaning of the street.

Omission in Specification.—Should any work be accidentally omitted herein, which may be fairly implied as included in the contract, of which the Engineer shall judge, the same shall be executed at the expense of the Contractor.

Responsibility of Contractor.—The Contractor shall have charge of, and be responsible for, the entire line of works until their completion and acceptance, and any unfaithful or imperfect work that may be discovered before the final acceptance of the work shall be corrected immediately on the requirement of the Engineer; notwithstanding that it may have been overlooked and estimated. The inspection of the work shall not relieve the Contractor from any of his obligations to perform sound and reliable work as herein described.

Contractor to Keep Works in Good Order.—The Contractor shall be liable for keeping in repair and good order the whole of the work executed by him, for nine months after date of completion.

Wherever the word "Engineer" is mentioned, it refers to the Engineer of the Sewer Commissioners or their author-

ized agents; and all explanations or directions necessary to the carrying out and completing satisfactorily the different descriptions of work contemplated and provided for under this contract, will be given by said Engineer.

The said Contractor hereby further agrees to sustain, by timbers and sufficient chains, all the water-pipes which may be affected in any manner by the work under this agreement, in their places without injury; and also to do every thing necessary to protect, support and sustain the gas-pipes, lamp-posts, service-pipes, and other gas-fixtures, laid in or across said streets, which may be liable to injury from digging the trenches for the work hereinbefore mentioned, and to have a sufficient quantity of timber and plank constantly on the ground, and to use the same as required, for bracing and sheeting the sides of the excavation; also to erect, and keep erect, a fence or railing across the ends and sides of the excavation, and place sufficient lights on or near the work, and keep them burning from twilight in the evening until sunrise, and shall employ a watchman as an additional security whenever the same may be needed.

Vary Work.—The work shall be carried on in such portions as the Engineer shall direct, and he shall have power also to vary, extend, or diminish the quantity of work, during its progress, without vitiating the contract; but no parts of the works shall be altered by the Contractor, from that shown on the drawings or described in the Specifications, without the express sanction of the Engineer in writing.

Material, Implements, Labor, etc.—All materials to be provided by the Contractor shall be of the best description, the pipes to conform in every particular to the Specification; and he shall furnish all efficient labor and implements necessary for the full and complete performance of his contract.

If any materials or implements should be brought to the ground which the Engineer may deem to be of improper description, or improper to be used in the work, the same shall be removed forthwith.

Shoring.—The Contractor shall, at his own expense, shore up, protect, restore, and make good, as may be necessary, all buildings, walls, fences, or other properties which may be disturbed or injured during the progress of the works; and the said Contractor will be held responsible for all damage which may happen to neighboring properties, or in any other way, from neglect of this precaution.

C.

DESCRIPTION OF CLAYS USED BY THE AKRON SEWER PIPE COMPANY, AKRON, OHIO.*

THE clays from which the Akron Sewer Pipe Company manufacture their pipe, appears to be a special deposit found only in this immediate vicinity, viz., within the corporate limits of Akron. This deposit has a face of some 500 feet, with a depth of 15 to 20 feet, comprising several distinct strata, which, when combined in proper proportions, tempered and ground under heavy iron wheels to the proper consistency, is then put under a very great pressure forced through dies, which form the pipe; is then placed on the driers, smoothed off inside and out, cut and straightened and otherwise finished, when it is placed in the kilns and subjected to a very high degree of heat, sufficient to vitrify it, and when done salt is thrown into and all through the kiln, which forms a flux with the surface of the pipe, giving it the glossy appearance, thereby rendering it perfectly impervious and indestructible to the action of water, earth, sewage-gases, or any known destroyer. These clays are on the surface with not more than from one to two feet of stripping or surface soil; then comes a very superior stratum of red brick clay, followed with a stratum of quite hard silicated rock; that in turn followed by a heavy stratum of shaly clay, which is highly impregnated with iron, with considerable mica; quite a quantity of kidney iron-ore is found in this stratum. Then follows a much harder shale,

* Description communicated by the manufacturers.

which is a bluish black. This also is impregnated with iron, and when ground as above is very tough and plastic. This stratum is underlaid by a much harder and blacker shale, and has some alumina in it. This last stratum, although when ground it is very tough and plastic, will not stand our fire test, and is therefore worthless; this exists to an untold depth. These different strata will *not alone* make good pipe, but combined as experience has taught us to do, we use the whole from the top red brick stratum to the last-named hard shale. We are inclined to think that the *iron* in our clay very materially adds to the strength of our pipe.

D.

DESCRIPTION OF THE CLAYS USED, AND THE METHOD PURSUED IN THE MANUFACTURE OF SEWER-PIPE IN THE NEIGHBORHOOD OF NEW YORK, BY G. W. RADER & CO.*

THE clays used in the manufacture, on the Atlantic border, are procured from the vicinity of Woodbridge and the Raritan River in New Jersey; and from geological surveys, are found to cover a strip of country about ten miles wide and fifty miles long extending from Staten Island Sound down to the Delaware River at Trenton, and thence probably into Pennsylvania and Maryland, although the mining of the article has been confined principally to the above district in New Jersey.

The deposits constitute some of the best material for the purpose to be found anywhere in the world, their formation being caused by the same natural processes, and from the same class of granitic rocks as the clays of Europe used for the same purpose.

The chemical composition of the clays generally used for stoneware is, alumina, silica, lime, magnesia, oxide of iron, potash, soda, water; and according as these are combined is the result arrived at. The hydrous-silicate of alumina (pure clay) is absolutely infusible in the greatest heat to which we can subject it, and silica or silicic acid is equally infusible. All fire-clays and those used in pottery combine these two elements in various degrees. Silica from 45 to 75

* Description communicated by the manufacturers.

per cent, alumina from 19 to 40 per cent, water 10 to 15 per cent, the other constituents enter about ¼ to 3 per cent each, though sometimes to a greater extent. If a clay be rich in alumina and silica, the alumina rather predominating, the alkalies being mostly absent, or present singly or in very limited quantities, the clay is very refractory; and is used for such wares (fire-brick, crucibles, etc.) as are required to withstand immense heat, but will not answer so well for stoneware goods, because their product is apt to be too porous or loose, except in the case of crucibles—other materials mixed with the clay tightens the body. A stoneware body, which is that required in a sewer-pipe, must be close, cohesive, hard, and strong to sustain the pressure to which it will be subjected; and to produce this result the alkalies, soda, potash, lime, iron, etc., must be present in the clay. The action of these is to semi-fuse or vitrify the mass by combining with the silica and acting in the nature of a flux.

The preparation of clay for sewer-pipe is not so particular an operation as to purification, as for that used for fine wares, because those ingredients which tend to discoloration, etc., are of no consequence in the pipe. The principal care is to get a clay or combine such clays as will produce the required body, and to exclude any metallic substances as will melt and run in the pipe, and any particles of limestone, as they will fly in the burning, and break the shell of the pipe. A thorough mixture is necessary to render the mass homogeneous, and this is one of the most essential points in the manufacture; and as all clays shrink in the burning more or less, clay which has been burnt, or damaged pipe, is ground up and incorporated with it. This stuff, called "grog," having been through the fire has shrunk all it will, and being added in proper

proportion forms the skeleton or frame of the pipe against which the fresh clay shrinks.

Keeping all the foregoing in view, it is necessary to test every lot of clay before using it, to find its elements, and to tell how to manipulate and combine it with others. It is almost impossible to find a clay ready formed by nature, which in itself is just right for the purpose it is required to serve.

The material is ground in a pug-mill till thoroughly and homogeneously mixed, and then passed to the press, whence the pipes issue through the dies under heavy pressure. They are then finished as to external appearance, etc., and allowed to stand a week or two as may be necessary till all excessive moisture is dried out of them, and then passed to the slip-tubs, where they receive their first coat of glaze. This glaze, commonly called slip, is a fusible clay obtained from Albany, N. Y., containing a large proportion of silica and the alkalies (and may be combined with other ingredients as may be advantageous), which, when subjected to a certain heat, forms the alkaline silicates which fuse with the silica on the surface of the pipe and vitrify. After the pipes are dipped in this slip, which dries on the pipe almost instantly, they are placed in the kilns and first subjected to a slow fire; after burning thus about 48 hours till the water held in combination is evaporated and the pipes are raised to a red heat, the fires are strengthened till the oven becomes heated to from 100° to 120° Wedgwood, equal to 14.077° to 16.677° Fahrenheit, which is one of the greatest heats required in any kind of pottery. When the pipes have nearly reached their highest temperature, common salt (chloride of sodium) is thrown in; the salt is volatilized and decomposed in the presence of moisture; hydrochloric acid is disengaged, and the pipes become covered with

silicate of soda, which, combining with the silicate of alumina (the clay) forms a very fusible double alkaline silicate or glaze on the surface of the pipe. This operation being finished, the kiln is then closed tight to prevent too rapid cooling, and at the end of four or five days the pipes are taken out finished.

It is evident that the glaze will not take till the body of the pipe has been brought to the point of incipient fusion and the fusible condition of the glaze corresponds as near as possible with this point, so that the efflorescence of the silicates near the surface of the pipe allows the glaze to be fused and partially absorbed in the surface. When in addition to this glaze salt is applied in the kiln, a thick or double glaze is formed. The point of fusion, as above, generally requires a very high heat, and produces a hard surface.

The principal utility of the glaze is to render the pipe non-absorbent and impervious, and to give it a smooth slippery surface as it were, so that the sewage will slide off with as little resistance as possible, thus preventing any deposit or choking up. It also protects the material of the pipe from the action of acids and makes it literally indestructible, which is proved to be the case by this kind of ware being much employed in chemical manipulations.

VALUES OF g BY FORMULA P. 54, FROM FRANCIS' HYDRAULIC EXPERIMENTS FOR THE SPECIFIED LATITUDES AND HEIGHTS ABOVE THE SEA.

HEIGHT ABOVE THE SEA IN FEET.	LATITUDES.						
	30°	35°	40°	45°	50°	55°	60°
0	32.1239	32.1383	32.1537	32.1695	32.1854	32.2008	32.2152
100	32.1236	32.1380	32.1534	32.1692	32.1851	32.2005	32.2149
200	32.1233	32.1377	32.1531	32.1689	32.1848	32.2002	32.2146
300	32.1129	32.1374	32.1528	32.1686	32.1845	32.1998	32.2143
400	32.1226	32.1371	32.1524	32.1683	32.1842	32.1995	32.2140
500	32.1228	32.1368	32.1521	32.1686	32.1839	32.1992	32.2137
600	32.1220	32.1364	32.1518	32.1677	32.1835	32.1989	32.2134
700	32.1217	32.1361	32.1515	32.1674	32.1832	32.1986	32.2131
800	32.1214	32.1358	32.1512	32.1671	32.1829	32.1983	32.2128
900	32.1211	32.1355	32.1509	32.1668	32.1826	32.1980	32.2125
1000	32.1208	32.1352	32.1506	32.1665	32.1823	32.1977	32.2121
1100	32.1205	32.1349	32.1503	32.1662	32.1820	32.1974	32.2118

LOSS OF HEAD BY FRICTION OF PIPE PER 1000 FEET ON THE UNDERMENTIONED SIZES, AND FOR THE GIVEN VELOCITIES, BY DARCY'S FORMULA FOR PIPE, P. 57.

VELOCITY IN FEET PER SECOND.	6 INCH DIAMETER.	8 INCH DIAMETER.	12 INCH DIAMETER.	16 INCH DIAMETER.	20 INCH DIAMETER.
.5	.180	.130	.083	.062	.048
1.	.721	.522	.335	.246	.195
1.5	1.623	1.171	.754	.554	.438
2.	2.885	2.087	1.340	.985	.779
2.5	4.509	3.261	2.093	1.540	1.217
3.	6.493	4.695	3.014	2.217	1.753
3.5	8.837	6.391	4.603	3.018	2.386
4.	11.542	8.347	5.360	3.942	3.116
4.5	14.608	10.565	6.782	4.989	3.944
5.	18.835	13.043	8.373	6.160	4.869
5.5	21.822	15.780	10.122	7.453	5.892
6.	25.970	18.782	12.058	8.870	7.012

VELOCITY IN FEET PER SECOND.	24 INCH DIAMETER.	30 INCH DIAMETER.	36 INCH DIAMETER.	40 INCH DIAMETER.	48 INCH DIAMETER.
.5	.040	.032	.026	.024	.019
1.	.161	.128	.106	.095	.079
1.5	.362	.287	.238	.214	.177
2.	.644	.511	.423	.380	.315
2.5	1.006	.798	.662	.594	.493
3.	1.449	1.151	.953	.855	.710
3.5	1.972	1.565	1.297	1.164	.966
4.	2.576	2.044	1.694	1.521	1.262
4.5	3.260	2.588	2.144	1.925	1.598
5.	4.026	3.195	2.648	2.376	1.972
5.5	4.871	3.865	3.204	2.875	2.387
6.	5.797	4.600	3.813	3.422	2.840